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INPUT-OUTPUT ANALYSIS OF THE

SOVIET CHEMICAL INDUSTRY

(III)

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CHLOROBENZENE, NITROBENZENE, ANILINE,  
ETHYLBENZENE, STYRENE, ISOPROPYLBENZENE,  
PHENOL, ACETONE, AND MONO NITROTOLUENES

Ten Process Reports

To

AC/S, INTELLIGENCE  
HEADQUARTERS, U.S. AIR FORCE

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### FOREWORD

The aromatic hydrocarbons, benzene, toluene and the isomeric xylenes, which are obtained from coke-oven gas and as by-products of petroleum refining, constitute the raw materials for a wide range of chemicals of importance in the manufacture of synthetic dyes, pharmaceuticals, insecticides, high-performance automotive and aircraft fuels, and a host of other miscellaneous products used by modern industry. Benzene is the most important of these hydrocarbons, toluene and the xylenes occupying considerably less-important positions.

Actually, relatively few basic methods are used to convert these aromatic hydrocarbons into intermediate materials for the manufacture of end products of the type mentioned above. Among the most important of the chemical techniques employed are halogenation (usually, chlorination), nitration, sulfonation and alkylation. Possible subsequent processing steps include hydrogenation, dehydrogenation, oxidation, amination, etc. While batch operation was once the customary manner of processing these materials, continuous operation is now favored in both the USSR and the US.

We present in this report ten process studies covering the most important Soviet methods for the manufacture of chlorobenzene, nitrobenzene, aniline, ethylbenzene, styrene, isopropylbenzene, phenol (including by-product acetone), and the mononitrotoluenes.

The material contained in this report is UNCLASSIFIED.

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## METHOD

## A. BATCH PROCESS

FIGURE VIII.A.1 FLOW DIAGRAM

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## B. CONTINUOUS PROCESS

FIGURE VIII.B.1 FLOW DIAGRAM

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LIST OF ABBREVIATIONS

ac	=	alternating current
amp	=	amperes
CM	=	cubic meters
cu ft	=	cubic feet
dc	=	direct current
diam	=	diameter
ea	=	each
°F	=	degrees Fahrenheit
ft	=	feet
gal	=	US gallons
gpm	=	US gallons per minute
hr	=	hours
in.	=	inches
KVA	=	kilovolt-amperes
KWH	=	kilowatt hours
lb	=	pounds mass
LMY	=	man years of labor
Man-Hr	=	man hours
MM BTU	=	million British thermal units
MT	=	metric tons
psi	=	pounds per square inch
psig	=	pounds per square inch gage
SCFM	=	standard cubic feet per minute (70°F, 1 atm)
TCM	=	thousand cubic meters
TD	=	thousand decaliters
TL	=	thousand pounds
TM	=	thousand meters
TMT	=	thousand metric tons
TMY	=	thousand man-years of labor
TU	=	thousand units
U	=	units
V	=	volts
XCF	=	million cubic feet
XKH	=	million kilowatt hours
XM	=	million meters
XMD	=	million man-days of labor
Yr	=	years

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SECTION I

CHLOROBENZENE

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### INTRODUCTION

Production of chlorobenzene is discussed in several Russian books which deal with chemical technology (1, 2, 3, 4) and in a monograph devoted entirely to this chemical (5). Information culled from these references, particularly Berkman's book (5), formed the basis for this report.

Volf'kovich (1) discussed the batch manufacture of chlorobenzene and then stated (1, p. 341): "--the most advantageous chlorination is by the continuous process; planning continuous production is one of the basic problems for the near future." Pavlov (2, p. 436) commented that "the continuous method of chlorinating benzene is of greatest interest." Berkman (5) considered continuous processing only.

The plant described in this report was consequently designed for the continuous mode of operation. A satisfactory energy and material balance was available (5). The plant size, 5000 metric tons per year, was estimated in the following way.

Berkman (5, pp. 102-104) compared the output efficiencies of four unspecified Soviet plants, and related the efficiency of their leading installation, Plant No. 1, to the performance of three East German factories. Production of one of the German plants was given (5, p. 7). A simple calculation indicated the annual capacity of a reactor of Plant No. 1 to be 4800 metric tons. This figure was confirmed by an independent estimate based on dimensions given for a benzene pump (5, pp. 78, 79). Assuming that a typical Soviet plant would contain only one reactor, the stated capacity was arrived at. This would correspond to an annual Soviet output of 15-20,000 metric tons of chlorobenzene from four plants, only one of which, Plant No. 1, was fully automated in 1957. (5) Moreover, the same reference makes it clear that a chlorobenzene plant must be directly associated with a source of inexpensive chlorine to be economical.

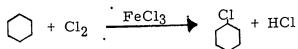
In view of the limited capacity of a chlorobenzene plant, the specialized nature of its equipment, and the relative importance of chlorobenzene itself, no substitution potential has been allocated to this system.

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PROCESS DESCRIPTION

The manufacture of chlorobenzene is based on the following reaction:



The raw materials for chlorobenzene production are benzene and chlorine, ferric chloride acting as a catalyst. The benzene used in the process must be free from sulfur compounds (thiophene, carbon di-sulfide) and water.

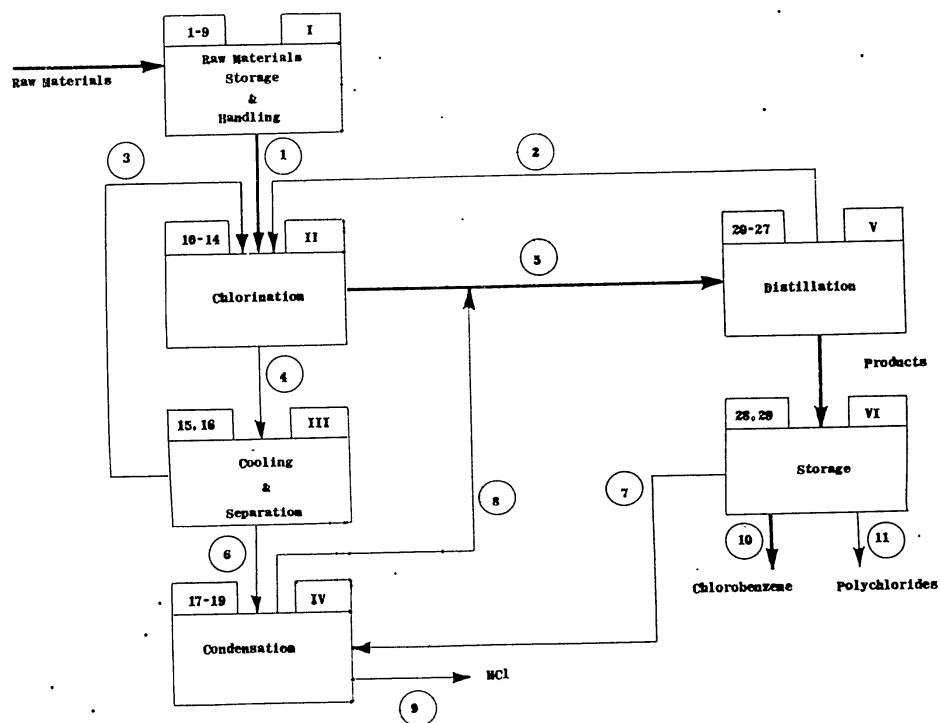
Benzene is dried in an initial distillation column and an excess is pumped into a packed reaction tower. Gaseous chlorine is introduced into the reactor separately. Ferric chloride is formed within the tower by chlorination of iron rings that constitute part of the packing. In some instances, ferrous chloride,  $\text{FeCl}_2$ , is pumped into the tower with the benzene, where it is oxidized to ferric chloride,  $\text{FeCl}_3$ , by the chlorine. The reactor capacity depends on rapid removal of the heat of reaction, (approximately 28 kcal per mol of  $\text{Cl}_2$ ). This is accomplished by evaporating some of the excess benzene and some chlorobenzene at a temperature of  $76^\circ - 83^\circ\text{C}$ . The reaction mass is removed from the tower before chlorination is complete in order to minimize polychloride formation. Unreacted benzene is stripped in a second distillation column and recycled to the reactor. The crude chlorobenzene is purified in a third distillation column where any polychlorides present are removed.

The controlling factors in the process are the reaction temperature and the rate of removal of the reaction mass from the tower. These variables control polychloride formation. Some di-substitution always occurs, the products being a mixture of mainly ortho- and para-isomers with very little of the meta-form. These byproducts find only limited use in the Soviet Union, chiefly as insecticides.

The production equipment in the plant is located in the open air. The entire process is automatically controlled with the exception of the benzene drying operation.

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FIGURE I.1  
CHLOROBENZENE



Flow Rates (lb/hr)											
Material	1	2	3	4	5	6	7	8	9	10	11
Benzene	1,058	2,822	1,750	1,896	2,872	148		128	13	4	
Chlorine	859										
Inerts	33			35		35			35		
Chlorobenzene		24	99	99	1,497		42	42		1,444	7
Polychlorides					64					7	60
HCl				485		485			478		
Loss									13	33	

NOTE: In the small blocks in the diagram above, Roman numerals refer to operations in TABLE I.2; Arabic numerals correspond to Process Equipment items.

#### PROCESS DATA

Standardized tables containing the results of our study of the Soviet process for the production of chlorobenzene are presented in this section. Tables I.1 - I.4, which follow, tabulate the process data in terms of input-output quantities.

While the technical details of the process have been drawn from Soviet practice (1-5), the equipment information has been derived primarily from US sources (6). Wherever possible, auxiliary-item inputs, such as piping, electricals, maintenance, etc., have been estimated from over-all factors derived from US experience, with appropriate adjustment for Soviet practice. Detailed descriptions of methods of sizing equipment and computing the corresponding values of weights and labor of installation are presented in our Chemical Process Calculation Manual (6). Where it has been necessary to approximate the input quantities for a special item of equipment, such as a furnace, or to estimate certain over-all factors from US practice, this is indicated by an asterisk (\*) following the item number in the Capital-Items table. In general, calculations of this nature will only be shown in our basic process-engineering worksheets.

Process information actually derived from Soviet sources is indicated by reference. We have provided for the estimation of major differences between US and Soviet practice by means of average labor- and weight-conversion factors. Thus, while the majority of the Capital-Items information is expressed on a US basis, the Capital-Summary figures are, for the most part, estimates of actual Soviet practice. The last is also true of the Material-Summary and General-Process-Items information. In general, we have been able to derive reliable estimates of Soviet items falling in CEIR Code Categories 02 (Machinery, Excluding Electrical), 03 (Electrical Machinery, Equipment and Supplies), 06 (Fabricated Metal Products), 07 (Chemicals), 08 (Metals, Primary and Secondary), 18 (Metal ores and Concentrates), 19 (Non-Metallic Minerals), as well as materials and labor involved in building construction.

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CHLOROBENZENETABLE I.1CAPITAL SUMMARY

<u>CEIR Code</u>	<u>CEIR Commodity Group</u>	<u>Quantity</u>	<u>Units</u>
0201	Machine Tools	1.50	MT
0209	Pumps and Compressors	0.240	MT
0217	Refrigeration Equipment	1.22	MT
0222	Industrial Machinery, NEC	14.7	MT
0225	Replacement Parts for Other 02 Commodities	0.609	MT
0301	Motors and Generators	0.150	MT
0305	Electrical Measurement and Control Apparatus	0.290	MT
0310	Electrical Machinery and Equipment, NEC	8.14	MT
0501	Mechanical Measuring and Control Instruments	0.387	MT
0610	Tanks	30.7	MT
0612	Metal Fabrication for Construction	0.0438	TMT
0717	Paints, Varnishes	0.675	MT
0805	Ordinary Steel Finished Shapes	0.0366	TMT
0806	Quality Steel Finished Shapes	0.00124	TMT
0808	Iron, Steel Forgings	0.00315	TMT
0809	Iron Castings	0.00180	TMT
0813	Primary Zinc	0.315	MT
0826	Non-Ferrous Rolling Drawing	0.0675	CM
0827	Non-Ferrous Casting	0.0675	CM
1010	Petroleum Coke Residuals, NEC	1.00176	TMT
1401	Round Timber	0.00744	TCM
1402	Saw Mill Products	0.0332	TMT
1403	Wood Products	0.06108	TMT
1404	Furniture	0.331	MT
1601	Refractories	0.00530	TMT
1603	Cement	0.0639	TMT
1604	Brick and Hollow Tile	0.110	TMT
1605	Gypsum Products	0.09324	TMT
1606	Lime	0.00688	TMT
1608	Flat Glass	0.600	MT
1609	Non-Metallic Construction Materials, NEC	0.166	TMT
1905	Stone, Sand, and Gravel	0.698	TMT
2300	Services (incl. Engineering) (US Basis) <sup>(a)</sup>	0.00496	TMY
2400	Labor (USSR Basis) <sup>(a)</sup>	0.0245	TMY

<sup>(a)</sup> See TABLE I.2, Footnote (d).

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CHLOROBENZENETABLE I.2CAPITAL ITEMS

<u>Item No.</u>	<u>Process Equipment<sup>(a)</sup></u>	<u>CEIR Code</u>	<u>Quantity<sup>(b)</sup></u>	<u>Installation Labor (Man-Hr)</u>
<u>Operation I - Raw Materials Storage and Handling</u>				
1	Storage Tank, Benzene (2; ea 30,000 gal)	0610	16.8	760
2	Azeotropic Drier (1 ft diam x 20 ft, ceramic ring packing)	0222 1601	1.56 0.22	120
3	Tank, Wet Benzene (200 gal)	0610	0.10	8
4	Pump, Centrifugal (3, ea 3.5 gpm @ 50 ft head)	0209 0301	0.24 0.15	30
5	Heat Exchanger (4.3 sq ft heat-transfer area)	0222	0.01	2
6	Condenser (10 sq ft heat-transfer area)	0222	0.02	4
7	Reboiler (10 sq ft heat-transfer area)	0222	0.32	4
8	Decanter (200 gal)	0610	0.10	8
9	Drying Tank, Benzene (200 gal, calcium-chloride-packed)	0610	0.10	8
<u>Operation II - Chlorination</u>				
10	Reactor Column (2 ft diam x 7.5 ft, packed with steel and ceramic rings; 3.5 ft diam x 9 ft disengaging section at top)	0222 0612 0805 1601	2.38 (0.27) 0.27 0.27	120
11	Tank, Dry Benzene (800 gal)	0610	0.38	18

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TABLE I. 2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Operation II - Chlorination (Continued)</u>				
12	Pump, Centrifugal (15 gpm @ 40 ft head, cast iron)	0209 0301	0.08 0.05	10
13	Constant Head Tank (100 gal)	0610	0.05	4
14	Drying Tank, Recycle Benzene (2; ea 400 gal, acid-resistant-tile-lined, calcium-chloride-packed)	0610	0.71	78
<u>Operation III - Cooling and Separation</u>				
15*	Cooler, Cascade Type (50 sq ft heat-transfer area, carbon, water cooled)	0310	0.07	14
16	Separator (50 gal)	0610	0.03	9
<u>Operation IV - Condensation</u>				
17	Column (2 ft diam x 10 ft, ceramic-ring packing)	0222 1601	2.02 0.44	120
18	Heat Exchanger (70 sq ft heat-transfer area)	0222	0.34	19
19	Tank (200 gal)	0610	0.10	8
<u>Operation V - Distillation</u>				
20	Distillation Column (2 ft diam x 38 ft, 25 plates @ 1.5 ft spacing)	0222	4.80	240
21	Condenser (52 sq ft heat-transfer area)	0222	0.08	15
22	Reboiler (140 sq ft heat-transfer area)	0222	1.10	32
23	Distillation Column (2 ft diam x 54 ft, 36 plates @ 1.5 ft spacing)	0222	6.06	240

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TABLE I. 2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Operation V - Distillation (Continued)</u>				
24	Condenser (20 sq ft heat-transfer area)	0222	0.04	7
25	Reboiler (75 sq ft heat-transfer area)	0222	0.73	20
26*	Scrubber (1 ft diam x 8 ft, carbon, packed with carbon rings)	0310	0.18	10
27	Steam Ejector (2)	0222	0.10	10
<u>Operation VI - Storage</u>				
28	Storage Tank, Chlorobenzene (2; ea 30,000 gal, vapor-proof)	0610	16.8	760
29	Storage Tank, Polychlorides (4; ea 5000 gal)	0610	5.76	308
Total Weight of Process Equipment (exclusive of CEIR Code 0612)			62.46MT	
Total Labor for Installation of Process Equipment				2,981
<u>Auxiliary Items</u>				
30	Improved Land			1,390
31	Refrigeration System	0217	1.63	365
32	Pipe, Valves and Fittings: Metal Fabrication for Construction Ordinary Steel Finished Shapes Quality Steel Finished Shapes Iron, Steel Forgings Iron Castings	0612 0805 0806 0808 0809	(29.7 ) 20.0 ) 1.65) 4.20) 2.5AT	

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TABLE I.2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Auxiliary Items (Continued)</u>				
	Primary Copper	0811	1.11 )	
	Primary Zinc	0813	0.420 )	
	Non-Ferrous Rolling, Drawing	0826	(0.090)(CM)	
	Non-Ferrous Casting	0827	(0.090)(CM)	4,170
	Non-Metallic Construction Material, NEC	1609		
33	Foundations for Equipment:			
	Reinforcing Rod	0612	(7.10 )	
		0805	7.10 )	
		1603	17.5 )	
	Cement	1905	150. )	720
	Sand, Stone, and Gravel			
		0717	0.675	625
34	Paint			
		1609	1.56	693
35	Insulation for Equipment and Piping			
		0612	(7.39)	
36	Structural Steel for Equipment	0805	7.39)	402
37	Electricals (Motors Less Than 5 hp and Miscellaneous Electrical Supplies)	0310	10.6	1,770
38	Instruments	0305	0.387)	
		0501	0.387)	555
39	Maintenance:			
	Machine Tools	0201	2.0	500
	Replacement Parts for Other 02 Commodities	0225	0.812	
40	Buildings (4000 sq ft floor area) <sup>(c)</sup>			
	Ordinary Steel Finished Shapes	0612	(10.5 )	
		0805	10.5 )	
	Petroleum Coke Residuals, NEC	1010	1.76 )	
	Round Timber	1410	7.44 )(CM)	

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TABLE I.2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Auxiliary Items (Continued)</u>				
	Saw-Mill Products	1402	33.2 )	
	Wood Products	1403	1.08 )	
	Cement	1603	46.4 )	
	Brick, Hollow Tile	1604	110. )	
	Gypsum Products	1605	3.24 )	
	Lime	1606	6.88 )	
	Flat Glass	1608	0.600)	
	Non-Metallic Construction Material, NEC	1609	164. )	
	Sand, Stone, and Gravel	1905	548. )	
	Office Furniture	1404	0.381)	19,700
41	Plant Transportation:			
	Truck	0406	1 (U)	
	Passenger Car	0407	1 (U)	
42	Services (Includes Engineering)	2300		11,900

Installation Labor Summary<sup>(d)</sup>

USSR Basis	2400	19,700
US Basis	2400	(14,200)
US Normalized to USSR Basis	2400	39,100
Total Installation Labor USSR Basis	2400	58,800

(a) Material of construction is mild steel unless otherwise specified. All equipment-weight and labor-of-installation data are US basis unless otherwise specified. A factor of 0.75 is used to convert the weight of metallic items in this table to the USSR basis presented in the Capital Summary table (6).

(b) Metric tons (MT) unless otherwise noted.

(c) Data are USSR basis except for the estimated floor area.

(d) Installation labor under Buildings is based on USSR practice; all other installation labor is based on US practice. The installation labor reported for CEIR Code 2400 in the Capital Summary table is on a USSR basis, US labor being converted to USSR labor by applying a normalizing factor of 2.75 (6). Labor under CEIR Code 2300 is on a US basis in all tables.

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CHLOROBENZENE

TABLE I.3

MATERIAL SUMMARY

Material	Material Input		CEIR Code	Specification
	Input/30 Days <sup>(a)</sup>			
	Quantity	Units		
Benzene	345	MT	1007	99.9% benzene
Chlorine	324	MT	0708	Liquid Cl <sub>2</sub> (96%)
Maintenance	1.62	MT	0225	Replacement parts

Material	Material Output		CEIR Code	Specification
	Output/30 Days <sup>(a)</sup>			
	Quantity	Units		
Chlorobenzene	475	MT	0714	99.5% chlorobenzene
Polychlorides	2.29	MT	0714	89.5% polychlorides
HCl	0.172	TMT	0711	90.8% HCl

(a) Operating days.

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CHLOROBENZENE

TABLE I.4

GENERAL PROCESS ITEMS

Rated annual capacity (99.5% Chlorobenzene),	4,750	MT <sup>(a)</sup>
Proportion of rated annual capacity realizable:		
1st year	75	%
2nd year	85	%
3rd year	95	%
4th year	98	%
Maximum realizable short term capacity	103	%
Labor input to process		
US Basis	48,000 <sup>(b)</sup>	Man-Hr/Yr
USSR Basis	144,000	Man-Hr/Yr <sup>(5)(b)</sup>
	72,000	Man-Hr/Yr <sup>(5)(c)</sup>
Labor scale factor	0 <sup>(d)(5)</sup>	
Range of applicability of scale factor:		
Lower limit	0.5 <sup>(e)</sup>	
Upper limit	2.0 <sup>(e)</sup>	
Electricity input per year	186,000	KWH
Water input per year	449,000	MT
Net fuel input per year	30.0	MM BTU
Process heat other than steam	—	MM BTU
Time required to build new plant	8	Months

(a) Based on 300 days per year operation at 100% mechanical efficiency.

(b) Assumes a non-automated plant.

(c) Assumes a fully-automated plant (i.e., like USSR Plant No. 1).

(d) Exponential factor for rated annual plant capacity.

(e) Multiplicative factor for rated annual plant capacity. STAT

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SECTION IINITROBENZENE

STAT

### INTRODUCTION

Nitrobenzene is universally manufactured by reaction of benzene with a mixture of nitric and sulfuric acids. Nitrobenzene itself is not of military importance, but any nitration plant is adaptable, with minor modifications, to the production of high explosives.

Several descriptions of nitrobenzene manufacturing techniques are available in the Russian literature. Pavlov (1) stated that continuous nitration by the process of Shchekotikhina has been used with great success; equipment designed for continuous processing by another Russian engineer, Kuberzhskii, was also described. The same author and others (2, 3) have discussed the batch process.

We have not located any statement of preference for a given process by USSR engineers. Consequently, this report contains one plant designed for batch, and a second for continuous operation.

Handling of spent acid is an important factor in the economics and operation of all nitration plants. In small factories, the acid may be discarded or fortified with oleum and re-used; on a larger scale, an acid-concentration unit is generally provided. In the plant described in this report, an acid recovery unit of moderate size was selected from Udyama's book (4). From the rated capacity of this recovery unit, 30-40 tons per day, a capacity for nitrobenzene was estimated at 30 tons per day (24 hours). Production of crude nitrobenzene, regularly used for manufacture of aniline (see our report for this chemical) and a purer, distilled product, have been arranged for in our plant design.

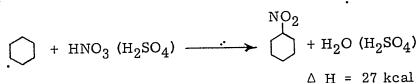
A nitrobenzene plant would probably operate as a section of a combine receiving its raw materials from a convenient source and producing several chemicals. It would be obviously economical to prepare aniline at the nitrobenzene source. As a second example, manufacture of chloro-nitrobenzenes, for which there is a small demand, could be readily integrated with a plant designed for nitrobenzene.

Elsewhere in this report we present a process study for mononitrotoluene, which is based on equipment of the same type as used for production of nitrobenzene.

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### PROCESS DESCRIPTION

The manufacture of nitrobenzene is based on the following reaction:



The raw materials for the production of nitrobenzene are benzene, nitric acid, and sulfuric acid. Although nitration may be conducted using nitric acid alone, the common industrial practice is to employ a mixed acid as indicated above. The sulfuric acid promotes the reaction by removing the water formed during the nitration. Accordingly, a measure of the effectiveness of the mixed acid is its dehydrating value (DVS) as expressed by the following formula:

$$\text{DVS} = \frac{\text{actual 100\% sulfuric acid}}{\text{water in reactants and water formed by nitration}}$$

Common European practice is to employ mixed acids of low DVS values requiring nitration times of 8 to 12 hours, as contrasted with the American reaction times of 3 to 4 hours for high-DVS mixed acids (5, 6). Both batch and continuous processes are used. The continuous process has been widely used in Europe for a number of years, whereas in the US the batch process is used almost exclusively. The equipment size will be less for a continuous process than for an equivalent batch process. From the standpoint of safety, there is an advantage to the continuous process due to the smaller amounts of reactants present during nitration.

Data for both continuous and batch processes taken from the Soviet literature are presented in this report (1, 4, 7). In both cases provision has been made for purification of the nitrobenzene and recovery of the spent sulfuric acid. A 24-hour capacity of 30 metric tons of nitrobenzene was chosen for both plants based on values reported in the Russian literature. This capacity is in agreement with figures given for spent-acid recovery plants (1). To obtain this capacity, four batch nitrators with the necessary separation and wash tanks are required, whereas

this productivity is readily obtained by a single nitrator of the continuous type. The continuous process described here is based on the Schmidt Meissner system and probably represents the most advanced Russian practice. Twenty percent of the nitrobenzene is purified by a single batch distillation over a 12-hour period. The remaining 80%, in accordance with American practice, is used as a raw material for the manufacture of aniline.

The recovery of the spent acid is an important part of the nitration process and is similar, except for slight differences in acid composition, for both plants. Acid recovery is effected by passing the spent acid through a packed column where nitrogen compounds are stripped by water and acid vapors from the retort. The gases are condensed in a spray condenser and exhausted to waste. The spent acid leaving the column enters a 3-compartment concentrator and flows countercurrent to the hot gases obtained from the combustion of liquid fuel. The acid is concentrated to 93%, and is cooled and stored for future use.

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METHOD A

NITROBENZENE

BATCH PROCESS

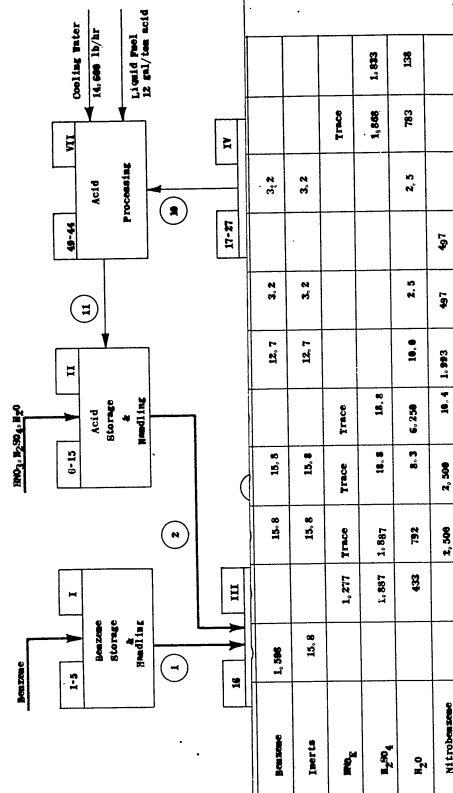
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Standardized tables containing the results of our study of the Soviet process for the production of nitrobenzene by a batch method are presented in this section. Tables II. A. 1 - II. A. 4, which follow, tabulate the process data in terms of input-output quantities.

While the technical details of the process have been drawn from German, Soviet and US practice (1-7), the equipment information has been derived primarily from US sources (8). Wherever possible, auxiliary-item inputs, such as piping, electricals, maintenance, etc., have been estimated from over-all factors derived from US experience, with appropriate adjustment for Soviet practice. Detailed descriptions of methods of sizing equipment and computing the corresponding values of weights and labor of installation are presented in our Chemical Process Calculation Manual (8). Where it has been necessary to approximate the input quantities for a special item of equipment, such as a furnace, or to estimate certain over-all factors from US practice, this is indicated by an asterisk (\*) following the item number in the Capital-Items table. In general, calculations of this nature will only be shown in our basic process engineering worksheets.

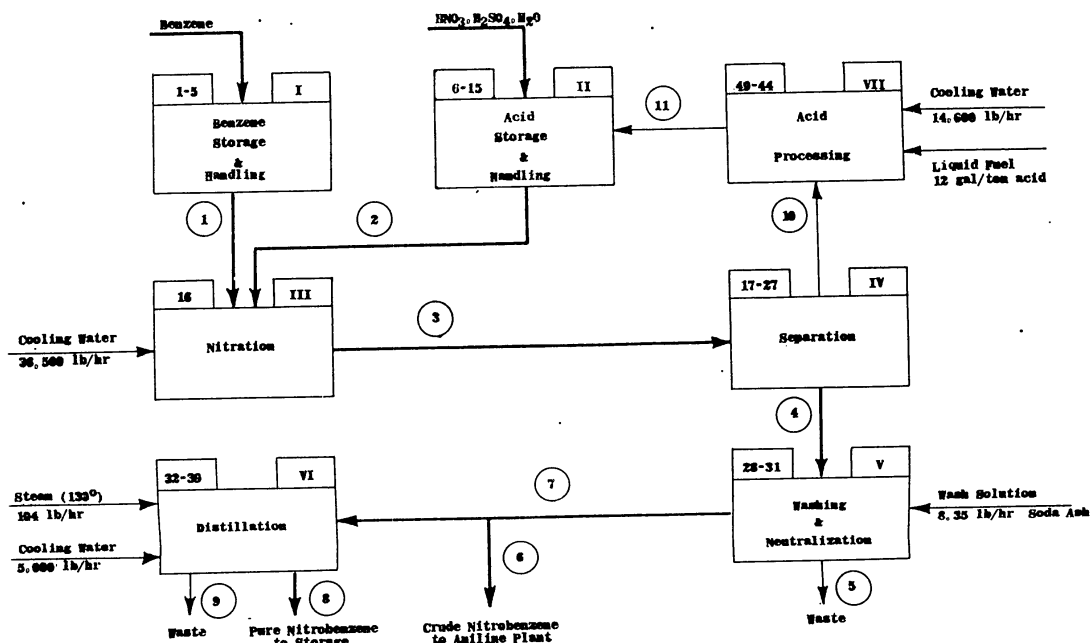
Process information actually derived from Soviet sources is indicated by reference. We have provided for the estimation of major differences between US and Soviet practice by means of average labor- and weight-conversion factors. Thus, while the majority of the Capital-Items information is expressed on a US basis, the Capital-Summary figures are, for the most part, estimates of actual Soviet practice. The last is also true of the Material-Summary and General-Process-Items information. In general, we have been able to derive reliable estimates of Soviet items falling in CEIR Code Categories 02 (Machinery, Excluding Electrical), 03 (Electrical Machinery, Equipment and Supplies), 06 (Fabricated Metal Products), 07 (Chemicals), 08 (Metals, Primary and Secondary), 18 (Metal Ores and Concentrates), 19 (Non-metallic Minerals), as well as materials and labor involved in building construction.

FIGURE 11. A. 1  
NITROBENZENE  
BATCH PROCESS



NOTE: In the block diagram above, Roman numerals refer to operations in TABLE II.A.2; Arabic numerals correspond to processes.

FIGURE II.A.1  
NITROBENZENE  
BATCH PROCESS



Flow Rates (lb/hr)											
Material	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Benzene	1,598		15.8	15.8		12.7	3.2		3.2		
Inerts	15.8		15.8	15.8		12.7	3.2		3.2		
$\text{HNO}_3$		1,277	Trace	Trace	Trace					Trace	
$\text{H}_2\text{SO}_4$		1,887	1,887	12.8	18.8					1,888	1,833
$\text{H}_2\text{O}$		433	792	8.3	6,250	10.0	2.5		2.5	783	138
Nitrobenzene			2,500	2,500	10.4	1,993	497	497			

NOTE: In the block diagram above, Roman numerals refer to Operations in TABLE II.A.2; Arabic numerals correspond to Process Equipment Items.

NITROBENZENEBATCH PROCESSTABLE II.A.1CAPITAL SUMMARY

<u>CEIR Code</u>	<u>CEIR Commodity Group</u>	<u>Quantity</u>	<u>Units</u>
0201	Machine Tools	1.50	MT
0209	Pumps and Compressors	1.16	MT
0222	Industrial Machinery, NEC	14.7	MT
0225	Replacement Parts for Other 02 Commodities	1.44	MT
0301	Motors and Generators	0.773	MT
0305	Electrical Measurement and Control Apparatus	0.690	MT
0310	Electrical Machinery and Equipment, NEC	18.9	MT
0406	Trucks	1	U
0407	Passenger Cars	1	U
0501	Mechanical Measuring and Control Instruments	0.690	MT
0610	Tanks	75.4	MT
0612	Metal Fabrication for Construction	0.104	TMT
0717	Paints, Varnishes	1.60	MT
0805	Ordinary Steel Finished Shapes	0.0860	TMT
0806	Quality Steel Finished Shapes	0.00309	TMT
0808	Iron, Steel Forgings	0.00746	TMT
0809	Iron Castings	0.00427	TMT
0811	Primary Copper	1.97	MT
0812	Primary Lead	0.645	MT
0813	Primary Zinc	0.746	MT
0826	Non-Ferrous Rolling, Drawing	0.221	CM
0827	Non-Ferrous Casting	0.161	CM
1010	Petroleum Coke Residuals, NEC	0.00432	TMT
		STAT	

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TABLE II.A.1 (Continued)

CEIR Code	CEIR Commodity Group	Quantity	Units
1401	Round Timber	0.0183	TCM
1402	Saw-Mill Products	0.0815	TMT
1403	Wood Products	0.00265	TMT
1404	Furniture	0.935	MT
1601	Refractories	0.017	TMT
1603	Cement	0.157	TMT
1604	Brick and Hollow Tile	0.269	TMT
1605	Gypsum Products	0.00795	TMT
1606	Lime	0.0169	TMT
1608	Flat Glass	1.47	MT
1609	Non-Metallic Construction Materials, NEC	0.406	TMT
1905	Stone, Sand, and Gravel	1.75	TMT
2300	Services (Incl. Engineering) (US Basis) <sup>(a)</sup>	0.00958	TMY
2400	Labor (USSR Basis) <sup>(a)</sup>	0.0524	TMY

(a)See Table II.A.2, Footnote (d).

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## NITROBENZENE

## BATCH PROCESS

TABLE II.A.2

## CAPITAL ITEMS

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Operation I - Benzene Storage and Handling</u>				
1	Storage Tank, Benzene (31,900 gal)	0612 0805	(5.0 ) 5.0 )	380
2	Pump, Centrifugal, Benzene (35 gpm @ 40 ft head)	0209 0301	0.04) 0.03)	5
3	Storage Tank, Benzene (5330 gal)	0610	1.55	70
4	Pump, Centrifugal, Benzene (4; ea 15 gpm @ 40 ft head)	0209 0301	0.16) 0.10)	20
5	Feed Tank, Benzene (4; ea 675 gal)	0610	1.3	60
<u>Operation II - Acid Storage and Handling</u>				
6	Storage Tank, Nitric Acid (24,000 gal, acid-resistant stainless steel)	0610	10.8	230
7	Pump, Centrifugal, Nitric Acid (25 gpm @ 75 ft head, acid-resistant)	0209 0301	0.08) 0.05)	10
8	Storage Tank, Nitric Acid (4000 gal, acid-resistant)	0610	1.2	55
9	Storage Tank, Sulfuric Acid (25,700 gal)	0610	7.8 STAT	200
10	Pump, Centrifugal, Sulfuric Acid (25 gpm @ 95 ft head, acid-resistant)	0209 0301	0.08) 0.05)	10

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TABLE II. A. 2 (Continued)

Item No.	Process Equipment(a)	CEIR Code	Quantity(b)	Installation Labor (Man-Hr)
<u>Operation II - Acid Storage and Handling (Continued)</u>				
11	Storage Tank, Sulfuric Acid (4330 gal)	0610	1.3 )	60
12	Metering Pump (2; acid-resistant)	0209 0301	0.08) 0.05)	10
13	Storage Tank, Mixed Acid (6380 gal, propeller-agitated, acid-resistant)	0610	1.8	80
14	Pump, Centrifugal, Mixed Acid (4; ea 15 gpm @ 85 ft head, acid-resistant)	0209 0301	0.32) 0.20)	20
15	Feed Tank, Mixed Acid (4; ea 825 gal, acid-resistant)	0610	1.5	75
<u>Operation III - Nitration</u>				
16	Nitrator (4, ea 250 cu ft, cast-iron; mild-steel cooling-jacket; cast-iron propeller stirrer; lead coils, 320 sq ft cooling area)	0610	22.6	300
<u>Operation IV - Separation</u>				
17	Separator (4; ea 1880 gal, mild-steel, lead-lined, conical bottom)	0610	7.21	142
18	Pump, Centrifugal, Acid Nitrobenzene (2; ea 15 gpm @ 50 ft head, acid-resistant)	0209 0301	0.08) 0.05)	10
19	Assembly Tank, Acid Nitrobenzene (4; ea 750 gal, mild-steel, lead-lined)	0610	4.01	68
20	Assembly Tank, Spent Acid (4; ea 1130 gal, mild-steel, lead-lined)	0610	5.6	100

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TABLE II. A. 2 (Continued)

Item No.	Process Equipment(a)	CEIR Code	Quantity(b)	Installation Labor (Man-Hr)
<u>Operation IV - Separation (Continued)</u>				
21	Pump, Centrifugal, Spent Acid (2; ea 40 gpm @ 20 ft head, acid-resistant)	0209 0301	0.08) 0.05)	10
22	Settling Tank, Spent Acid (2; ea 4500 gal, mild-steel, lead-lined)	0610	7.87	120
23	Pump, Centrifugal, Acid Nitrobenzene (1 gpm @ 20 ft head, acid-resistant)	0209 0301	0.04) 0.03)	5
24	Assembly Tank, Acid Nitrobenzene (37.5 gal, mild-steel, lead-lined)	0610	0.31	3
25	Pump, Centrifugal, Spent Acid (2, ea 75 gpm @ 20 ft head, acid-resistant)	0209 0301	0.08) 0.05)	10
26	Storage Tank, Spent Acid (2; ea 4500 gal, mild-steel, lead-lined)	0610	7.87	120
27	Pump, Centrifugal, Spent Acid (5 gpm @ 50 ft head, acid-resistant)	0209 0301	0.04) 0.03)	5
<u>Operation V - Washing and Neutralization</u>				
28	Washer, Propeller Agitated, Acid Nitrobenzene (2; ea 4500 gal, mild-steel, lead-lined)	0610	7.87	120
29	Solution Tank, Propeller Agitated, Soda Ash (3000 gal)	0610	3.05	46
30	Pump, Centrifugal, Nitrobenzene (2; ea 15 gpm @ 20 ft head)	0209 0301	0.08) 0.05)	10
31	Assembly Tank, Crude Nitrobenzene (2; ea 1900 gal)	0610	3.57	68

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TABLE II. A. 2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Operation VI - Distillation</u>				
32	Pump, Centrifugal, Nitrobenzene (20 gpm @ 20 ft head)	0209 0301	0.04) 0.03)	5
33	Batch Still (1000 lb/hr; 6 ft diam x 14 ft; 10 mm Hg working pressure; 3 plate dephlegmator 0.5 ft diam x 3 ft; 33 sq ft heating area)	0222	15.0	490
34	Ejector (25 mm pressure for still)	0209	0.1	10
35	Condenser (1000 lb/hr, 25 sq ft cooling area)	0222	0.5	16
36	Cooler (1000 lb/hr, 25 sq ft cooling area)	0222	0.5	16
37	Pump, Centrifugal, Pure Nitrobenzene (2 gpm @ 20 ft head)	0209 0301	0.04) 0.03)	5
38	Storage Tank, Pure Nitrobenzene (7500 gal)	0610	2.1	90
39	Tank (37.5 gal, for forerunnings)	0610	0.02	4
<u>Operation VII - Acid Processing</u>				
40	Retort (5.3 ft diam x 23.5 ft, 3 compartments, lead-lined steel with lining of acid-resistant brick, direct contact of fuel gas with counter-current acid flow, 500°F operating temperature)	0209 0222 0301 0612 0805 0806 0812 0826 1601	0.16) 0.59) 0.20) (3.47) 2.30) 0.21) 0.86) (0.08) (CM) 17.00)	461

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TABLE II. A. 2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Operation VII - Acid Processing (Continued)</u>				
41	Cooler, 93% Sulfuric Acid (20 cu ft; 66 sq ft cooling area)	0222	3.07	7
42	Measuring Tank, Spent Acid (225 gal; spent-acid feed to denitrating column; acid-resistant)	0610	0.1	8
43	Pump, Centrifugal, 93% Sulfuric Acid (5 gpm @ 50 ft head, acid-resistant)	0209 0301	0.04) 0.03)	5
44	Storage Tank, 93% Sulfuric Acid (3750 gal)	0610	1.14	55
Total Weight of Process Equipment (exclusive of CEIR Code 0612 and 0826)				148.18 MT
Total Labor for Installation of Process Equipment				3,594
<u>Auxiliary Items</u>				
45	Improved Land			3,290
46	Pipe, Valves and Fittings:			
	Metal Fabrication for Construction	0612	(70.4 )	
	Ordinary Steel Finished Shapes	0805	47.2 )	
	Quality Steel Finished Shapes	0806	3.91 )	
	Iron, Steel Forgings	0808	9.95 )	
	Iron Castings	0809	5.69 )	
	Primary Copper	0811	2.63 )	
	Primary Zinc	0813	0.995 )	
	Non-Ferrous Rolling, Drawing	0826	( 0.214) (CM)	
	Non-Ferrous Casting	0827	( 0.214) (STATI)	
	Non-Metallic Construction Material, NEC1609		0.640)	9,870

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TABLE II. A. 2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Auxiliary Items (Continued)</u>				
47	Foundations for Equipment: Reinforcing Rod	0612	(17.0 )	
		0805	17.0 )	
	Cement	1603	42.5 )	
	Sand, Stone, and Gravel	1905	395. )	1,750
48	Paint	0717	1.60 )	1,480
49	Insulation for Equipment and Piping	1609	3.71	1,650
50	Structural Steel for Equipment	0612	( 8.91 )	
		0805	8.91 )	485
51	Electricals (Motors less than 5 hp and miscellaneous electrical supplies)	0310	25.2 )	4,210
52	Instruments	0305	0.92 )	
		0501	0.92 )	1,310
53	Maintenance: Machine Tools	0201	2.00	500
	Replacement Parts for Other 02 Commodities	0225	1.92	-
54	Buildings (9820 sq ft floor area) <sup>(c)</sup>			
	Ordinary Steel Finished Shapes	0612	(25.7 )	
		0805	25.7 )	
	Petroleum Coke Residuals, NEC	1010	4.32 )	
	Round Timber	1401	18.3 ) (CM)	
	Saw Mill Products	1402	81.5 )	
	Wood Products	1403	2.65 )	
	Cement	1603	114. )	
	Brick, Hollow Tile	1604	269. )	
	Gypsum Products	1605	7.95 )	
	Lime	1606	16.9 )	

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TABLE II. A. 2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Auxiliary Items (Continued)</u>				
54	Buildings: (Continued)			
	Flat Glass	1608	1.47 )	
	Non-Metallic Construction			
	Material, NEC	1609	402. )	
	Sand, Stone, and Gravel	1905	1,350. )	
	Office Furniture	1404	0.935 )	48,400
55	Plant Transportation:			
	Truck	0406	1 (U)	
	Passenger Car	0407	1 (U)	
56	Services (Includes Engineering)	2300		23,000
<u>Installation Labor Summary<sup>(d)</sup></u>				
	USSR Basis	2400		48,400
	US Basis	2400		(28,100)
	US Normalized to USSR Basis	2400		77,300
Total Installation Labor USSR Basis				125,700

(a) Material of construction is mild steel unless otherwise specified. All equipment-weight and labor-of-installation data are US basis unless otherwise specified. A factor of 0.75 is used to convert the weight of metallic items in this table to the USSR basis presented in the Capital Summary table (8).

(b) Metric tons (MT) unless otherwise noted.

(c) Data are USSR basis except for the estimated floor area.

(d) Installation labor under Buildings is based on USSR practice; all other installation labor is based on US practice. The installation labor reported for CEIR Code 2400 in the Capital Summary table is on a USSR basis, US labor being converted to USSR labor by applying a normalizing factor of 2.75 (8). Labor under CEIR Code 2300 is on a US basis in all tables.

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NITROBENZENEBATCH PROCESSTABLE II. A. 3MATERIAL SUMMARY

Material	Material Input		CEIR Code	Specification
	Input/30 Days(a)			
	Quantity	Units		
Benzene	527.0	MT	1007	Technical (99% Benzene)
H <sub>2</sub> SO <sub>4</sub>	0.192	TMT	0703	Commercial (92% H <sub>2</sub> SO <sub>4</sub> )
HNO <sub>3</sub>	0.511	TMT	0704	Commercial (81.4% HNO <sub>3</sub> )
Na <sub>2</sub> CO <sub>3</sub>	2.86	MT	0705	Technical (95% Na <sub>2</sub> CO <sub>3</sub> )
Maintenance	0.947	MT	0225	Replacement parts

Material	Material Output		CEIR Code	Specification
	Output/30 Days(a)			
	Quantity	Units		
Nitrobenzene	163.0	MT	0714	Pure (100% Nitrobenzene)
Nitrobenzene	662.0	MT	0714	Crude (98.2% Nitrobenzene)

(a) Operating days.

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NITROBENZENEBATCH PROCESSTABLE II. A. 4GENERAL PROCESS ITEMS

Rated Annual Capacity, Pure Nitrobenzene	1,630	MT <sup>(a)</sup>
Crude (98.2%) Nitrobenzene	6,620	MT <sup>(a)</sup>
Proportion of rated annual capacity realizable:		
1st year	75	%
2nd year	85	%
3rd year	95	%
4th year	98	%
Maximum Realizable Short Term Capacity	103	%
Labor Input to Process <sup>(b)</sup> :		
US Basis	186,000	Man-Hr/Yr
USSR Basis	560,000	Man-Hr/Yr <sup>(8)</sup>
Labor Scale Factor	0.7 <sup>(c)</sup>	
Range of applicability of scale factor:		
Lower limit	0.2 <sup>(d)</sup>	
Upper limit	2.0 <sup>(d)</sup>	
Electrical Input per Year	888,000	KWH
Water Input per Year	4,378,000	MT
Net Fuel Input per Year (as steam)	21,500	MM BTU
Process Heat Other Than Steam	11,000	MM BTU
Time Required to Build New Plant	8	Months

(a) Based on 300 days per year operation at 100% mechanical efficiency.

(b) Assumes a non-automated plant.

(c) Exponential factor for rated annual plant capacity.

(d) Multiplicative factor for rated annual plant capacity.

STAT

METHOD B

NITROBENZENE

CONTINUOUS PROCESS

STAT

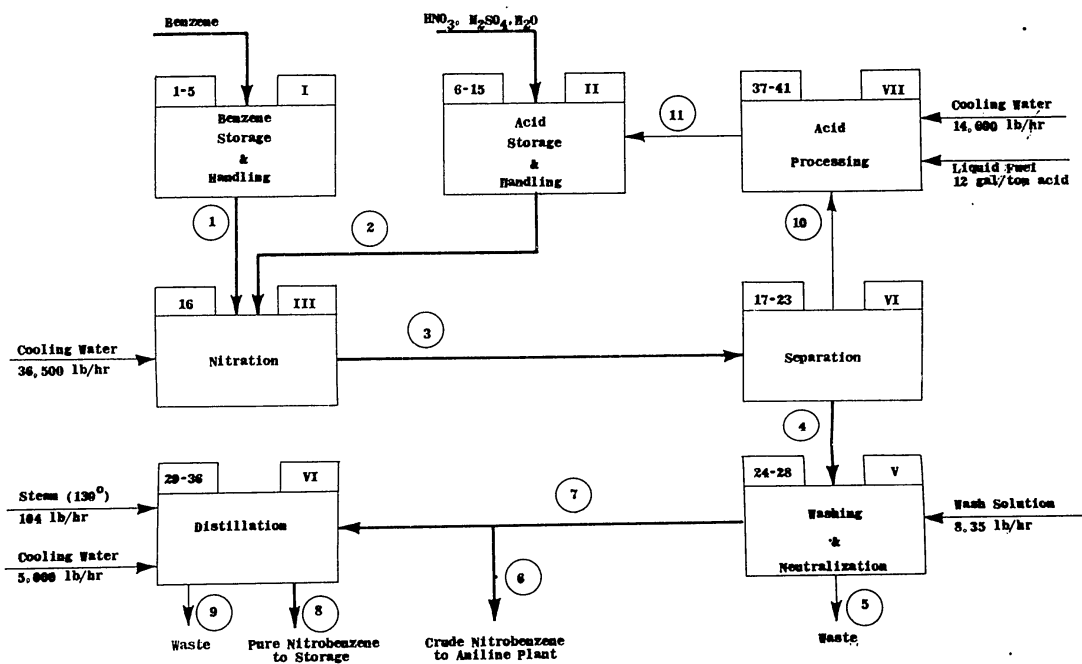
### PROCESS DATA

Standardized tables containing the results of our study of the Soviet process for the production of nitrobenzene by a continuous process are presented in this section. Tables II. B. 1 - II. B. 4 which follow, tabulate the process data in terms of input-output quantities.

While the technical details of the process have been drawn from German, Soviet and US practice (1-7), the equipment information has been derived primarily from US sources (8). Wherever possible, auxiliary-item inputs, such as piping, electricals, maintenance, etc., have been estimated from over-all factors derived from US experience, with appropriate adjustment for Soviet practice. Detailed descriptions of methods of sizing equipment and computing the corresponding values of weights and labor of installation are presented in our Chemical Process Calculation Manual (8). Where it has been necessary to approximate the input quantities for a special item of equipment, such as a furnace, or to estimate certain over-all factors from US practice, this is indicated by an asterisk (\*) following the item number in the Capital-Items table. In general, calculations of this nature will only be shown in our basic process engineering worksheets.

Process information actually derived from Soviet sources is indicated by reference. We have provided for the estimation of major differences between US and Soviet practice by means of average labor- and weight-conversion factors. Thus, while the majority of the Capital-Items information is expressed on a US basis, the Capital-Summary figures are, for the most part, estimates of actual Soviet practice. The last is also true of the Material-Summary and General-Process-Items information. In general, we have been able to derive reliable estimates of Soviet items falling in CEIR Code Categories 02 (Machinery, excluding Electrical), 03 (Electrical Machinery, Equipment and Supplies), 06 (Fabricated Metal Products), 07 (Chemicals), 08 (Metals, Primary and Secondary), 18 (Metal Ores and Concentrates), 19 (Non-Metallic Minerals), as well as materials and labor involved in building construction.

FIGURE II.B.1  
NITROBENZENE  
CONTINUOUS PROCESS



Flow Rates (lb/hr)											
Material	1	2	3	4	5	6	7	8	9	10	11
Benzene	1,598		15.8	15.8		12.7	3.2		3.2		
Inerts	15.8		15.8	15.8		12.7	3.2		3.2		
HNO <sub>3</sub>		1,300	12.9	Trace	Trace					12.9	12.9
H <sub>2</sub> SO <sub>4</sub>		2,475	2,475	19.4	19.4					2,456	2,417
H <sub>2</sub> O		646	1,025	6.5	6,250	10.0	2.5		2.5	1,019	182
Nitrobenzene			2,500	2,500	10.4	1,993	497	497			

NOTE: In the block diagram above, Roman numerals refer to operations in TABLE II.B.2; Arabic numerals correspond to Process Equipment Items

NITROBENZENECONTINUOUS PROCESSTABLE II.B.1CAPITAL SUMMARY

<u>CEIR Code</u>	<u>CEIR Commodity Group</u>	<u>Quantity</u>	<u>Units</u>
0201	Machine Tools	1.50	MT
0209	Pumps and Compressors	0.683	MT
0222	Industrial Machinery, NEC	15.5	MT
0225	Replacement Parts for Other 02 Commodities	0.938	MT
0301	Motors and Generators	0.503	MT
0305	Electrical Measurement and Control Apparatus	0.450	MT
0310	Electrical Machinery and Equipment, NEC	12.2	MT
0406	Trucks	1	U
0407	Passenger Cars	1	U
0501	Mechanical Measuring and Control Instruments	0.443	MT
0610	Tanks	36.4	MT
0612	Metal Fabrication for Construction	0.0705	TMT
0717	Paints, Varnishes	1.04	MT
0805	Ordinary Steel Finished Shapes	0.0583	TMT
0806	Quality Steel Finished Shapes	0.00206	TMT
0808	Iron, Steel Forgings	0.00484	TMT
0809	Iron Castings	0.00277	TMT
0811	Primary Copper	1.28	MT
0812	Primary Lead	0.645	MT
0813	Primary Zinc	0.484	MT
0826	Non-Ferrous Rolling, Drawing	0.164	CM
0827	Non-Ferrous Casting	0.104	CM
1010	Petroleum Coke Residuals, NEC	0.00286	TMT
		STAT	

TABLE II. B.1 (Continued)

CEIR Code	CEIR Commodity Group	Quantity	Units
1401	Round Timber	0.0121	TCM
1402	Saw-Mill Products	0.0539	TMT
1403	Wood Products	0.00175	TMT
1404	Furniture	0.618	MT
1601	Refractories	0.017	TMT
1603	Cement	0.101	TMT
1604	Brick and Hollow Tile	0.178	TMT
1605	Gypsum Products	0.00526	TMT
1606	Lime	0.0112	TMT
1608	Flat Glass	0.974	MT
1609	Non-Metallic Construction Materials, NEC	0.268	TMT
1905	Stone, Sand, and Gravel	1.11	TMT
2300	Services (Including Engineering)(US Basis)(a)	0.00683	TMY
2400	Labor (USSR Basis)(a)	0.0351	TMY

(a) See Table II. B.2, Footnote (d).

## NITROBENZENE

## CONTINUOUS PROCESS

TABLE II. B.2

## CAPITAL ITEMS

Item No.	Process Equipment (a)	CEIR Code	Quantity (b)	Installation Labor (Man-Hr)
Operation I - Benzene Storage and Handling				
1	Storage Tank, Benzene (31,900 gal)	0612 0805	( 5.0 ) 5.0 )	380
2	Pump, Centrifugal, Benzene (35 gpm @ 40 ft head)	0209 0301	0.04) 0.03)	5
3	Storage Tank, Benzene (5330 gal)	0610	1.55	70
4	Pump, Centrifugal, Benzene (15 gpm @ 40 ft head)	0209 0310	0.04) 0.03)	5
5	Feed Tank, Benzene (675 gal)	0610	0.3	17
Operation II - Acid Storage and Handling				
6	Storage Tank, Nitric Acid (24,000 gal, acid-resistant, stainless steel)	0610	10.8	230
7	Pump, Centrifugal, Nitric Acid (25 gpm @ 75 ft head, acid-resistant)	0209 0301	0.08) 0.05)	10
8	Storage Tank, Nitric Acid (4000 gal, acid-resistant)	0610	1.2	55
9	Storage Tank, Sulfuric Acid (25,700 gal)	0610	7.8	200
10	Pump, Centrifugal, Sulfuric Acid (25 gpm @ 95 ft head, acid-resistant)	0209 0301	0.08) 0.05) STAT	10

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TABLE II, B, 2 (Continued)

Item No.	Process Equipment(a)	CEIR Code	Quantity(b)	Installation Labor (Man-Hr)
<u>Operation II - Acid Storage and Handling (Continued)</u>				
11	Storage Tank, Sulfuric Acid (4330 gal)	0610	1.3	60
12	Metering Pump (2; acid-resistant)	0209 0301	0.08 0.05	10
13	Storage Tank, Mixed Acid (6380 gal, propeller-agitated, acid-resistant)	0610	1.8	80
14	Pump, Centrifugal, Mixed Acid (15 gpm @ 85 ft head, acid-resistant)	0209 0301	0.04 0.03	5
15	Feed Tank, Mixed Acid (825 gal, acid-resistant)	0610	0.4	20
<u>Operation III - Nitration</u>				
16	Nitrator, Schmidt-Meissner Type (110 gal, stainless-steel, with propeller and cooling coils, 50 sq ft heat-transfer area)	0610	0.38	15
<u>Operation IV - Separation</u>				
17	Separator, Schmidt-Meissner Type (15 cu ft tank with vanes, stainless-steel; constant-head overflow device for nitrobenzene)	0222	0.2	13
18	Settling Tank, Spent Acid (2; ea 7000 gal, mild-steel, lead-lined)	0610	9.4	170
19	Assembly Tank, Acid Nitrobenzene (37.5 gal; mild-steel, lead-lined)	0610	0.21	3
20	Pump, Centrifugal, Acid Nitrobenzene (1 gpm @ 20 ft head, acid-resistant)	0209 0301	0.04 0.03	5

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TABLE II, B, 2 (Continued)

Item No.	Process Equipment(a)	CEIR Code	Quantity(b)	Installation Labor (Man-Hr)
<u>Operation IV - Separation (Continued)</u>				
21	Pump, Centrifugal, Spent Acid (2; ea 75 gpm @ 20 ft head, acid-resistant)	0209 0301	0.08 0.05	10
22	Storage Tank, Spent Acid (2; ea 4500 gal, mild-steel, lead-lined)	0610	7.87	120
23	Pump, Centrifugal; Spent Acid (5 gpm @ 50 ft head, acid-resistant)	0209 0301	0.04 0.03	5
<u>Operation V - Washing and Neutralization</u>				
24	Washer, Schmidt-Meissner Type, Acid Nitrobenzene (3; ea 10 cu ft, stainless-steel column with 10 plates, air-agitated)	0222	0.3	60
25	Air Compressor (2 SCFM @ 10 ft head)	0209 0301	0.01 0.03	2
26	Separator, Schmidt-Meissner Type, Nitrobenzene (3; ea 113 gal, stainless-steel)	0222	0.45	40
27	Solution Tank, Propeller Agitated, Soda Ash (1100 gal)	0610	0.9	30
28	Assembly Tank, Crude Nitrobenzene (2; ea 1900 gal)	0610	1.32	68
<u>Operation VI - Distillation</u>				
29	Pump, Centrifugal, Nitrobenzene (20 gpm @ 20 ft head)	0209 0301	0.04 0.03	5
30	Batch Still (1000 lb/hr, 6 ft diam x 14 ft, 10 mm Hg, working pressure, 3 plate dephlegmator, 0.5 ft diam x 3 ft, 33 sq ft heating area)	0222	15.0	490

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TABLE II. B. 2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Operation VI - Distillation (Continued)</u>				
31	Ejector (25 mm pressure for still)	0209	0.1	10
32	Condenser (1000 lb/hr, 25 sq ft cooling area)	0222	0.5	16
33	Cooler (1000 lb/hr, 25 sq ft cooling area)	0222	0.5	16
34	Pump, Centrifugal, Pure Nitrobenzene (2 gpm @ 20 ft head)	0209 0301	0.04 0.03	5
35	Storage Tank, Pure Nitrobenzene (7500 gal)	0610	2.1	90
36	Tank (37.5 gal, for forerunnings)	0610	0.02	4
<u>Operation VII - Acid Processing</u>				
37	Retort (5.3 ft diam x 23.5 ft, 3 compartments, lead-lined steel with lining of acid-resistant brick, direct contact of fuel gas with countercurrent acid flow, 500°F operating temperature)	0209 0222 0301 0612 0805 0806 0812 0826 1601	0.16 0.59 0.20 ( 3.47) 2.30 0.21 0.86 ( 0.08) (CM) 17.00	461
38	Cooler, 93% Sulfuric Acid (20 cu ft, 66 sq ft cooling area)	0222	3.07	7
39	Measuring Tank, Spent Acid (225 gal, spent acid feed to denitrating column, acid-resistant)	0610	0.1	8

TABLE II. B. 2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Operation VII - Acid Processing (Continued)</u>				
40	Pump, Centrifugal, 93% Sulfuric Acid (5 gpm @ 50 ft head, acid-resistant)	0209 0301	0.04 0.03	5
41	Storage Tank, 93% Sulfuric Acid (3750 gal)	0610	1.14	55
<u>Auxiliary Items</u>				
42	Improved Land			2,130
43	Pipe, Valves and Fittings: Metal Fabrication for Construction Ordinary Steel Finished Shapes Quality Steel Finished Shapes Iron, Steel Forgings Iron Castings Primary Copper Primary Zinc Non-Ferrous Rolling, Drawing Non-Ferrous Casting Non-Metallic Construction Material, NEC	0612 0805 0806 0808 0809 0811 0813 0826 0827 1609	(45.7 ) 30.7 ) 2.54) 6.45) 3.69) 1.71) 0.645) ( 0.139) (CM) 0.139) (CM) 0.416)	6,410
44	Foundations for Equipment: Reinforcing Rod	0612 0805	(10.0 ) (10.0 )	

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TABLE II. B. 2 (Continued).

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Auxiliary Items (Continued)</u>				
44	Foundations for Equipment: (Continued)	1603	25.5 )	
	Cement	1905	225. )	1,100
	Sand, Stone, and Gravel			
		0717	1.04	960
45	Paint			
		1609	2.40	1,070
46	Insulation for Equipment and Piping			
		0612	( 7.12 )	
47	Structural Steel for Equipment	0805	7.12 )	387
48	Electricals (Motors less than 5 hp and miscellaneous electrical supplies)	0310	16.3	2,730
49	Instruments	0305	0.60 )	
		0501	0.59 )	853
50	Maintenance:			
	Machine Tools	0201	2.00	500
	Replacement Parts for Other 02 Commodities	0225	1.25	
51	Buildings (6490 sq ft floor area) <sup>(c)</sup>	0612	17.0 )	
	Ordinary Steel Finished Shapes	0805	17.0 )	
		1010	2.86 )	
	Petroleum Coke Residuals, NEC	1401	12.1 ) (CM)	
	Round Timber	1402	53.9 )	
	Saw Mill Products	1403	1.75 )	
	Wood Products	1603	75.3 )	
	Cement	1604	178. )	
	Brick, Hollow Tile	1605	5.26 )	
	Gypsum Products	1606	11.2 )	
	Lime	1608	0.974 )	
	Flat Glass	1609	265. )	
	Non-Metallic Construction Material, NEC	1905	889. )	
	Sand, Stone, and Gravel	1404	0.618 )	32,000 <sup>(c)</sup>
	Office Furniture			

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TABLE II. B. 2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Auxiliary Items (Continued)</u>				
52	Plant Transportation:			
	Truck	0406	1 (U)	
	Passenger Car	0407	1 (U)	
53	Services (Includes Engineering)	2300		16,400
<u>Installation Labor Summary<sup>(d)</sup></u>				
	USSR Basis	2400		32,000
	US Basis	2400		(19,010)
	US Normalized to USSR Basis	2400		52,300
Total Installation Labor USSR Basis				84,300

(a) Material of construction is mild steel unless otherwise specified. All equipment-weight and labor-of-installation data are US basis unless otherwise specified. A factor of 0.75 is used to convert the weight of metallic items in this table to the USSR basis presented in the Capital Summary table (8).

(b) Metric tons (MT) unless otherwise noted.

(c) Data are USSR basis except for the estimated floor area.

(d) Installation labor under Buildings is based on USSR practice; all other installation labor is based on US practice. The installation labor reported for CEIR Code 2400 in the Capital Summary table is on a USSR basis, US labor being converted to USSR labor by applying a normalizing factor of 2.75 (8). Labor under CEIR Code 2300 is on a US basis in all tables.

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NITROBENZENE  
CONTINUOUS PROCESS

TABLE II. B. 3  
MATERIAL SUMMARY

<u>Material Input</u>				
<u>Material</u>	<u>Input/30 Days(a)</u>		<u>CEIR Code</u>	<u>Specification</u>
	<u>Quantity</u>	<u>Units</u>		
Benzene	527.0	MT	1007	Technical (99% Benzene)
H <sub>2</sub> SO <sub>4</sub>	0.0206	TMT	0703	Commercial (92% H <sub>2</sub> SO <sub>4</sub> )
HNO <sub>3</sub>	0.569	TMT	0704	Commercial (73.7% HNO <sub>3</sub> )
Na <sub>2</sub> CO <sub>3</sub>	2.86	MT	0705	Technical (95% Na <sub>2</sub> CO <sub>3</sub> )
Maintenance	0.614	MT	0225	Replacement parts

<u>Material Output</u>				
<u>Material</u>	<u>Output/30 Days(a)</u>		<u>CEIR Code</u>	<u>Specification</u>
	<u>Quantity</u>	<u>Units</u>		
Nitrobenzene	163.0	MT	0714	Pure (100% Nitrobenzene)
Nitrobenzene	662.0	MT	0714	Crude (98.2% Nitrobenzene)

(a) Operating days.

NITROBENZENE  
CONTINUOUS PROCESS

TABLE II. B. 4

GENERAL PROCESS ITEMS

Rated Annual Capacity, Pure Nitrobenzene	1,630	MT <sup>(a)</sup>
Crude (98.2%) Nitrobenzene	6,620	MT <sup>(a)</sup>
Proportion of rated annual capacity realizable:		
1st year	78	%
2nd year	85	%
3rd year	95	%
4th year	98	%
Maximum Realizable Short Term Capacity	103	%
Labor Input to Process <sup>(b)</sup> :		
US Basis	129,000	Man-Hr/Yr
USSR Basis	387,000	Man-Hr/Yr <sup>(8)</sup>
Labor Scale Factor	0.7 <sup>(c)</sup>	
Range of applicability of scale factor:		
Lower limit	0.2 <sup>(d)</sup>	
Upper limit	2.0 <sup>(d)</sup>	
Electrical Input per Year	807,000	KWH
Water Input per Year	4,378,000	MT
Net Fuel Input per Year (as steam)	21,500	MM BTU
Process Heat Other Than Steam	14,400	MM BTU
Time Required to Build New Plant	8	Months

(a) Based on 300 days per year operation at 100% mechanical efficiency.

(b) Assumes a non-automated plant.

(c) Exponential factor for rated annual plant capacity.

(d) Multiplicative factor for rated annual plant capacity.

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SECTION IIIANILINE

STAT

### INTRODUCTION

Available Soviet literature disclosed three processes for the production of aniline: reduction of nitrobenzene with iron and an acid; reduction of nitrobenzene with hydrogen; and reaction of chlorobenzene with ammonia (1, 2, 3).

The first process is described in detail in these references. Pavlov(3) stated that considerable amounts of aniline are obtained from chlorobenzene, but did not say that this comment applied to the USSR; Volf'kovich (2) also made a vague statement about the latter process, and Zykov(1) simply stated that the reaction proceeds in 90% yield at 200-230°C under a pressure of 70 atmospheres. In view of the many demands on the 15-20,000 metric-ton annual output of chlorobenzene, i.e., for use as a solvent and in the manufacture of DDT, dyes, phenol and salicylate preparations, we have assumed that any diversion of this material to the production of aniline would be slight.

Concerning reduction of nitrobenzene with hydrogen, both Pavlov, in 1947(3), and Volf'kovich, in 1946(2), predicted that the process would replace the other available methods. Zykov, in 1955(1), stated that reduction with hydrogen was currently replacing the use of iron and acid.

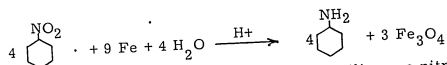
In spite of these statements, we have concluded from the proportion of space allotted to the reduction with iron and acid in the above books and in others(4) that this process is now and will continue to be of major importance in the USSR. If additional information on the catalytic procedure is obtained, it may prove necessary to design a separate plant for this process.

It is assumed that approximately 80% of Russian nitrobenzene production is used to manufacture aniline, as is the case in the US. The plant described in this report thus produces approximately 5000 metric tons of aniline per year (see our report on nitrobenzene).

While an aniline plant of this type might be adapted to the production of other materials, such as dye intermediates of the toluidine type, because of the greater importance of aniline itself, we have not assigned a significant substitution potential to this system.

PROCESS DESCRIPTION

The production of aniline by the iron-acid reduction of nitrobenzene is based on the following reaction:

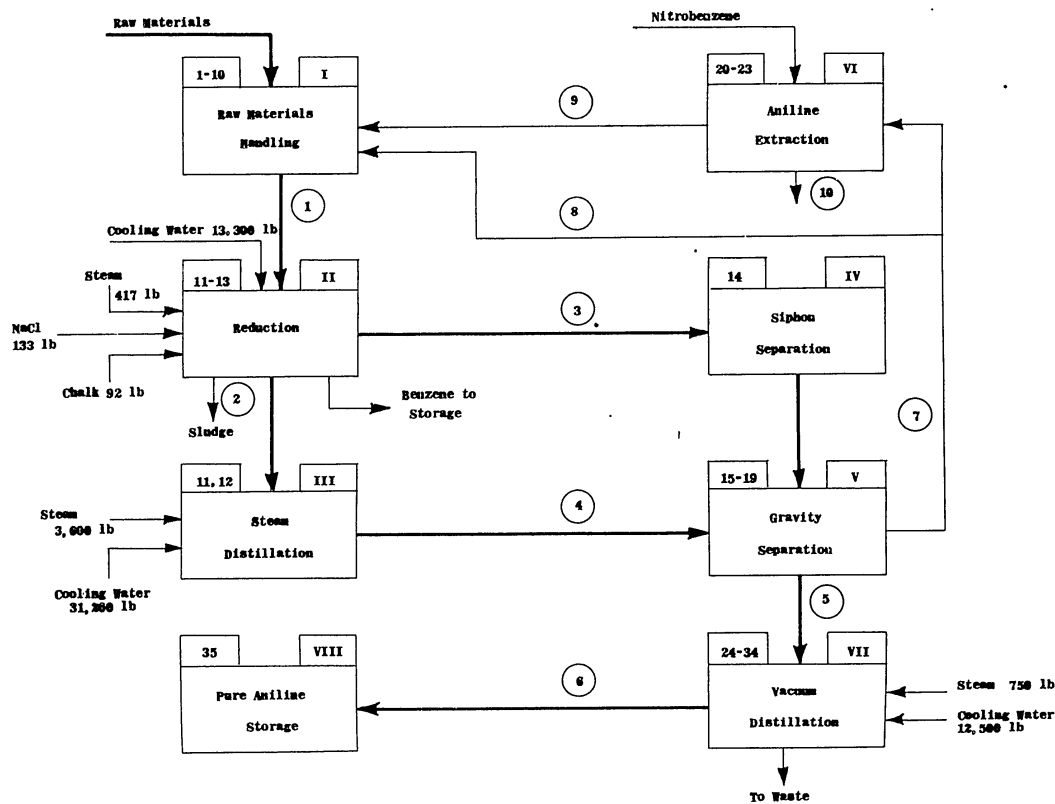


The raw materials for the production of aniline are nitrobenzene, iron, water, and an electrolyte such as hydrochloric acid. The electrolyte, although not shown in the above reactions, catalyzes the reduction. A quantity of three to four pounds of hydrochloric acid is sufficient to reduce 100 pounds of nitrobenzene (1).

About 25% of the reactants are charged to the reducer initially, the remainder being added over a period of about 9 hours. After the addition of reactants is completed, an additional three hours are required to complete the reaction. Although the reaction is highly exothermic, live steam is added to the reducer to start and complete the reaction. Throughout the reaction, the aniline and water distilled from the reducer are condensed and returned to the reducer. The condenser temperature is kept sufficiently high to allow benzene vapors to pass off. At the end of the reaction, the reaction mass is neutralized and sufficient salt is added to cause a separation into aniline and water layers. Approximately 60% of the aniline is siphoned off into settling tanks. The remaining aniline is removed by steam distillation, a separation of the water and aniline being effected in settling tanks (3).

A portion of the water, containing approximately 3% aniline, is used to charge the reducers. The remainder of the water is extracted with nitrobenzene to remove aniline and is discharged to waste. Pure aniline is produced from the crude product by vacuum distillation. The sludge from the reducer, consisting mainly of mixed iron oxides, can be used for production of iron-oxide pigments. The most important operation in the production of aniline is its separation from the reaction mass.

FIGURE III.A.1  
ANILINE  
NITROBENZENE-REDUCTION PROCESS  
(Iron-Acid)



Flow Rate (lb/hr)										
Material	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Nitrobenzene	2,000	4	13	4	17				637	2
Fe (10 Mesh)	2,500	475								
HCl	117									
Aniline	108		965	640	1,490	1,467	115	47	64	4
H <sub>2</sub> O	1,350	1,800	62	3,600	80		3,582	1,350		2,232
Fe <sub>3</sub> O <sub>4</sub>		2,800								
Benzene	13								6	

NOTE: In the block diagram above, Roman numerals refer to Operations in TABLE III.A.2; Arabic numerals correspond to Process Equipment Items.

### PROCESS DATA

Standardized tables containing the results of our study of the Soviet process for the production of aniline by the iron-acid reduction of nitrobenzene are presented in this section. Tables III.1-III.4, which follow, tabulate the process data in terms of input-output quantities.

While the technical details of the process have been drawn from Soviet practice (1-4), the equipment information has been derived primarily from US sources (5). Wherever possible, auxiliary-item inputs, such as piping, electricals, maintenance, etc., have been estimated from over-all factors derived from US experience, with appropriate adjustment for Soviet practice. Detailed descriptions of methods of sizing equipment and computing the corresponding values of weights and labor of installation are presented in our Chemical-Process Calculation Manual (5). Where it has been necessary to approximate the input quantities for a special item of equipment, such as a furnace, or to estimate certain over-all factors from US practice, this is indicated by an asterisk (\*) following the item number in the Capital-Items table. In general, calculations of this nature will only be shown in our basic process engineering worksheets.

Process information actually derived from Soviet sources is indicated by reference. We have provided for the estimation of major differences between US and Soviet practice by means of average labor- and weight-conversion factors. Thus, while the majority of the Capital-Items information is expressed on a US basis, the Capital-Summary figures are, for the most part, estimates of actual Soviet practice. The last is also true of the Material-Summary and General-Process-Items information. In general, we have been able to derive reliable estimates of Soviet items falling in CEIR Code Categories 02 (Machinery, Excluding Electrical), 03 (Electrical Machinery, Equipment and Supplies), 06 (Fabricated Metal Products), 07 (Chemicals), 08 (Metals, Primary and Secondary), 18 (Metal Ores and Concentrates), 19 (Non-Metallic Minerals), as well as materials and labor involved in building construction.

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ANILINENITROBENZENE-REDUCTION PROCESS  
(Iron-Acid)TABLE III.1CAPITAL SUMMARY

<u>CEIR Code</u>	<u>CEIR Commodity Group</u>	<u>Quantity</u>	<u>Units</u>
0201	Machine Tools	4.50	MT
0209	Pumps and Compressors	1.70	MT
0222	Industrial Machinery, NEC	24.2	MT
0225	Replacement Parts for Other 02 Commodities	2.18	MT
0301	Motors and Generators	0.765	MT
0305	Electrical Measurement and Control Apparatus	1.19	MT
0310	Electrical Machinery and Equipment, NEC	21.8	MT
0406	Truck	1	U
0407	Passenger Car	1	U
0603	Heating and Cooking Apparatus (Small Boilers)	0.00158	TMT
0610	Tanks	26.5	MT
0612	Metal Fabrication for Construction	0.154	TMT
0717	Paints, Varnishes	1.85	MT
0805	Ordinary Steel Finished Shapes	0.134	TMT
0806	Quality Steel Finished Shapes	0.00339	TMT
0808	Iron, Steel Forgings	0.00863	TMT
0809	Iron Castings	0.00493	TMT
0811	Primary Copper	2.28	MT
0813	Primary Zinc	0.863	MT
0826	Non-Ferrous Rolling, Drawing	0.185	CM
0827	Non-Ferrous Casting	0.185	CM
0903	Industrial Rubber Products	0.150	MT
1010	Petroleum Coke Residuals, NEC	0.00524	TMT

TABLE III.1 (Continued)

<u>CEIR Code</u>	<u>CEIR Commodity Group</u>	<u>Quantity</u>	<u>Units</u>
1401	Round Timber	0.0221	TCM
1402	Saw Mill Products	0.0988	TMT
1403	Wood Products	0.00321	TMT
1404	Furniture	1.30	MT
1603	Cement	0.192	TMT
1604	Birch and Hollow Tile	0.326	TMT
1605	Gypsum Products	0.00964	TMT
1606	Lime	0.0205	TMT
1608	Flat Glass	1.79	MT
1609	Non-Metallic Construction Materials, NEC	0.494	TMT
1905	Stone, Sand, and Gravel	2.09	TMT
2300	Services (incl. Engineering)(US Basis) <sup>(a)</sup>	0.0106	TMY
2400	Labor (USSR Basis) <sup>(a)</sup>	0.0645	TMY

<sup>(a)</sup>See TABLE III, A, 2, Footnote (d).

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ANILINENITROBENZENE-REDUCTION PROCESS  
(Iron-Acid)TABLE III. 2CAPITAL ITEMS

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Operation I - Raw Materials Handling</u>				
1	Storage Tank, Nitrobenzene (28,900 gal)	0612 0805	(7) 7	370
2	Storage Tank, 30% Hydrochloric Acid (750 gal, acid-resistant)	0610 0903	0.4 0.05	17 86
3	Storage Tank, Aniline-Water (3750 gal)	0222	1.2	95
4	Storage Bin, Iron Filings (3000 cu ft, 10 mesh)	0612 0805 1603 1905	(36.4) 36.4 7.3 37.8	268
5	Hopper and Automatic Feeder, Iron Filings (5; ea 1500 lb/hr)	0222 0301	2.3 0.15	500 12
6	Pump, Centrifugal, Nitrobenzene (5; ea 20 gpm @ 50 ft head)	0209 0301	0.4 0.15	50
7	Feed Tank, Nitrobenzene (5; ea 975 gal)	0222	2.0	100
8	Pump, Centrifugal, Hydrochloric Acid (5; 5 gpm @ 50 ft head, acid-resistant)	0209 0301	0.4 0.15	50
9	Feed Tank, Hydrochloric Acid (5; ea 187.5 gal, acid-resistant)	0601 0903	0.48 0.1	33 175
10	Pump, Centrifugal, Aniline-Water (5; ea 15 gpm @ 50 ft head)	0209 0301	0.4 0.15	50

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TABLE III. 2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Operation II - Reduction</u>				
11	Reducer (5; ea 700 cu ft, cast iron, 2 in. thick insulation; cast-iron paddle agitator with hollow shaft for steam addition; 1 ft diam x 12 ft cast-iron column leading to condenser)	0610 1609	20.8 2	750 580
12	Condenser, Tubular (5; ea 960 sq ft heat-transfer area)	0222	6.5	700
13	Condenser, Benzene (5; ea 7 sq ft heat-transfer area)	0222	0.08	15
<u>Operation III - Steam Distillation</u>				
11 & 12 <sup>(c)</sup>	Reducers & Tubular Condensers (5; used for steam distillation)		(c)	(c)
<u>Operation IV - Siphon Separation</u>				
14	Tank, Siphoned Aniline (2; ea 1500 gal)	0610	1.2	56
<u>Operation V - Gravity Separation</u>				
15	Settling Vessel, Aniline-Water (2; ea 7500 gal)	0610	3.6	170
16	Tank, Crude Aniline (2; ea 2250 gal)	0610	1.6	74
17	Tank, Aniline-Water (2; ea 5250 gal)	0610	3.5	134
18	Filter, Gravity, Nutsche Type (2)	0222 1905	0.2 1.4	20
19	Pump, Centrifugal (2; ea 5 gpm @ 50 ft head; siphoned aniline to settling vessel)	0209 0301	.16 .06	20
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TABLE III.2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Operation VI - Aniline Extraction</u>				
20	Extraction Tank (2; ea 3750 gal, agitated; aniline-water extracted with nitrobenzene)	0610	3.2	96
21	Pump, Centrifugal (2; ea 95 gpm @ 20 ft head; aniline-water to extraction tank)	0209 0301	0.16 0.06	20
22	Pump, Centrifugal (2; ea 15 gpm @ 20 ft head; nitrobenzene to extraction tank)	0209 0301	0.16 0.06	20
23	Pump, Centrifugal, Nitrobenzene-Aniline (2; ea 15 gpm @ 20 ft head)	0209 0301	0.16 0.06	20
<u>Operation VII - Vacuum Distillation</u>				
24	Still (2000 lb/hr, 600 cu ft boiler, 85 mm Hg working pressure; 11 plate bubble cap column, 5 ft diam x 15 ft, steam-heated, 170 sq ft coil area)	0222 0603	15 1.5	470 35
25	Reflux Condenser (2000 lb/hr, 30% reflux, 100 sq ft heat-transfer area)	0222	0.3	25
26	Cooler (2000 lb/hr, 50 sq ft heat-transfer area)	0222	0.2	14
27	Tank (1125 gal, residue storage)	0610	0.48	22
28	Still (2000 lb/hr, 150 cu ft boiler, 85 mm working pressure; column 2.4 ft diam x 12 ft, packed with 8 mm Raschig rings, 50 sq ft steam heated area, residue distillation)	0222 0603	2.6 0.6	240 14
29	Reflux Condenser (2000 lb/hr, 100 sq ft heat-transfer area)	0222	0.3	25

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TABLE III.2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Operation VII - Vacuum Distillation (Continued)</u>				
30	Cooler (2000 lb/hr, 50 sq ft heat-transfer area)	0222	0.3	14
<u>Operation VIII - Storage</u>				
31	Ejectors (2; for vacuum on stills)	0222	0.1	16
32	Pump, Centrifugal, Crude Aniline (2; 40 gpm @ 20 ft head)	0209 0301	0.16 0.06	20
33	Pump, Centrifugal (20 gpm @ 50 ft head residue to still)	0209 0301	0.08 0.03	10
34	10 hp Pump, Cooling Water (111 gpm @ 100 ft head)	0209 0301	0.18 0.19	15
35	Storage Tank, Pure Aniline (26,300 gal)	0612 0805	(7) 7	350
Total Weight of Process Equipment (exclusive of CEIR Code 0612)			170.67 MT	
Total Labor for Installation of Process Equipment				5,751
<u>Auxiliary Items</u>				
36	Improved Land			3,800
37	Pipe, Valves and Fittings:			
	Metal Fabrication for Construction	0612	(81.4 )	
	Ordinary Steel Finished Shapes	0805	54.6 )	
	Quality Steel Finished Shapes	0806	4.52 )	
	Iron, Steel Forgings	0808	11.5 )	
	Iron Castings	0809	8.57 )	
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TABLE III.2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Auxiliary Items (Continued)</u>				
	Primary Copper	0811	3.04)	
	Primary Zinc	0813	1.15)	
	Non-Ferrous Rolling, Drawing	0826	(0.246)(CM)	
	Non-Ferrous Casting	0827	(0.246)(CM)	
	Non-Metallic Construction Material, NEC	1609	0.739	11,400
38	Foundations for Equipment:			
	Reinforcing Rod	0612	(18.0 )	
		0805	18.0 )	
	Cement	1603	47.0 )	
	Sand, Stone, and Gravel	1905	425. )	2,000
39	Paint	0717	1.85	1,710
40	Insulation for Equipment and Piping	1609	4.28	1,900
41	Structural Steel for Equipment	0612	(14.3 )	
		0805	14.3 )	776
42	Electricals (Motor less than 5 hp and miscellaneous electrical supplies)	0310	29.1	4,860
43	Instruments	0305	1.59	1,140
44	Maintenance:			
	Machine Tools	0201	6.0	1,500
	Replacement Parts for Other 02 Commodities	0225	2.91	
45	Buildings (11,900 sq ft floor area) <sup>(c)</sup>			
	Ordinary Steel Finished Shapes	0612	(31.2 )	
		0805	31.2 )	
		1010	5.24)	
	Petroleum Coke Residuals, NEC	1401	22.1 ) (CM)	
	Round Timber	1402	98.8 )	
	Saw Mill Products	1403	3.21)	
	Wood Products	1603	138. )	
	Cement			

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TABLE III.2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Auxiliary Items (Continued)</u>				
	Brick, Hollow Tile	1604	326. )	
	Gypsum Products	1605	9.64)	
	Lime	1606	20.5 )	
	Flat Glass	1608	1.79)	
	Non-Metallic Construction Material, NEC	1609	487. )	
	Sand, Stone, and Gravel	1905	1,630. )	
	Office Furniture	1404	1.13)	58,700 <sup>(c)</sup>
46	Plant Transportation:			
	Delivery Cart (2)	0222	1.30)	30
	Truck	0406	.1 (U)	
	Passenger Car	0407	1 (U)	
47	Services (Includes Engineering)	2300		25,500
<u>Installation Labor Summary<sup>(d)</sup></u>				
	USSR Basis	2400		58,700
	US Basis	2400		(34,900)
	US Normalized to USSR Basis	2400		96,000
	Total Installation Labor USSR Basis	2400		154,700

(a) Material of construction is mild steel unless otherwise specified. All equipment-weight and labor-of-installation data are US basis unless otherwise specified. A factor of 0.75 is used to convert the weight of metallic items in this table to the USSR basis presented in the Capital-Summary table (5).

(b) Metric tons (MT) unless otherwise noted.

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(d) Data are USSR basis except for the estimated floor area.

(e) Installation labor under Buildings is based on USSR practice; all other installation labor is based on US practice. The installation labor reported for CEIR Code 2400 in the Capital Summary table is on a USSR basis, US labor being converted to USSR labor by applying a normalizing factor of 2.75 (5). Labor under CEIR Code 2300 is on a US basis in all tables.

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ANILINENITROBENZENE-REDUCTION PROCESS  
(Iron-Acid)TABLE III. 3MATERIAL SUMMARY

Material Input				
Material	Input/30 Days (a)		CEIR Code	Specification
	Quantity	Units		
Nitrobenzene	553.	MT	0714	98.2% nitrobenzene
Benzene	2.29	MT	1007	99% benzene
Iron Granules	0.816	TMT	0711	10-mesh
HCl	0.123	TMT	0711	31% HCl
NaCl	0.0434	TMT	0711	Technical
Chalk	0.300	TMT	0711	Technical
Maintenance	1.57	MT	0225	Replacement parts
Material Output				
Material	Output/30 Days (a)		CEIR Code	Specification
	Quantity	Units		
Aniline	478	MT	0714	Pure
Sludge	1,659	MT	9711	Fe <sub>2</sub> O <sub>3</sub> , Fe, CaCO <sub>3</sub> , NaCl, H <sub>2</sub> O, etc.

(a) Operating days.

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ANILINENITROBENZENE-REDUCTION PROCESS  
(Iron-Acid)TABLE III. 4GENERAL PROCESS ITEMS

Rated Annual Capacity	4,780	MT <sup>(a)</sup>
Percent of rated annual capacity realization:		
1st year	75	%
2nd year	85	%
3rd year	95	%
4th year	98	%
Maximum Realizable Short Term Capacity	103	%
Labor Input to Process <sup>(b)</sup>		
US Basis	147,000	Man-Hr/Yr
USSR Basis	441,000	Man-Hr/Yr (5)
Labor Scale Factor	0.7 <sup>(c)</sup>	
Range of applicability of scale factor:		
Lower limit	0.2 <sup>(d)</sup>	
Upper limit	2.0 <sup>(d)</sup>	
Electrical Input Per Year	316,000	KWH
Water Input Per Year	190,000	MT
Net Fuel Input Per Year	34,200	MM BTU
Process Heat Other Than Steam	-	MM BTU
Time Required to Build New Plant	6	Months

(a) Based on 300 days per year operation at 100% mechanical efficiency.

(b) Assumes a non-automated plant.

(c) Exponential factor for rated annual plant capacity.

(d) Multiplicative factor for rated annual plant capacity.

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SECTION IVETHYLBENZENE(FRIEDEL-CRAFTS SYNTHESIS)

### INTRODUCTION

Ethylbenzene is the precursor of styrene, a chemical basic for the manufacture of styrene plastics and of great importance in the production of synthetic rubber, for example the Soviet "SKS" types. Ethylbenzene itself might be used as an additive in aviation gasoline.

Production of ethylbenzene was discussed briefly by Barg (1), Yukelson (2), Kryuchkov (3), Smirnov (4), and Gorin (5) and in some detail by Dalin et al (6). From these references it was possible to set up a flow-sheet and material balance for the process. Although the references suggested that both aluminum chloride and phosphoric acid are used as catalysts in the synthesis, use of the former appeared to be preferred (6, 2).

The ethylbenzene unit described in this report was sized to satisfy a styrene requirement of 19-20,000 metric tons per year. Our justification for this plant size is contained in our report on styrene, which follows immediately this discussion of ethylbenzene.

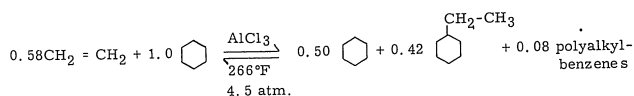
The German plant which operated at Schkopau, near Leipzig, Germany, in World War II, is very similar to the plant described herein (7). A major difference is that the USSR uses ethylene diluted with ethane (6). The diluent gas appears to be inert.

The process for manufacture of ethylbenzene resembles closely that used for isopropylbenzene (see our process report on isopropylbenzene). A plant equipped to produce one of these chemicals could no doubt be adapted to production of the other.

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PROCESS DESCRIPTION

The manufacture of ethylbenzene, using the Friedel-Crafts method of synthesis, is based on the following reaction:



The equation represents the approximate equilibrium conditions within the reactor for the temperature and pressure indicated. Under these conditions of equilibrium, 50% of the benzene reacts on a mol basis; of this, 42% goes to monoethylbenzene and 8% to polyalkylbenzenes. To maintain this equilibrium within the reactor and to insure the over-all production of monoethylbenzene from the benzene and ethylene input to the process, the polyalkylbenzenes and the unreacted benzene are separated from the product and recycled to the reactor.

The raw materials for ethylbenzene production are benzene, ethylene and aluminum chloride. The benzene, which has been purified to remove sulfur compounds, such as thiophene and carbon disulfide, is usually obtained as a by-product from coke-oven gas. Ethylene is obtained as a by-product gas stream from petroleum refining. The gas stream, as received, has a composition of approximately 65% ethylene and 35% ethane. Aluminum chloride catalyzes the reaction and is recycled as a catalyst complex. A small amount of moisture-free aluminum chloride must continuously be added to make up for losses during the process.

The raw benzene is received at the plant in tank cars and is pumped to a distillation column for drying. Water is removed in the overhead product as a benzene-water azeotrope that is condensed and settled. The benzene layer is recycled to the drying column, while the water is discarded. A small amount of dry benzene is sent to a mixing tank where dry aluminum chloride is added to it, together with a small amount of the catalyst promoter, ethyl chloride, to form the make-up catalyst complex. The catalyst complex is a reddish oil that has a specific gravity greater than unity. It is practically insoluble in hydrocarbons. The make-up catalyst complex and the dry benzene are then sent to the alkylation column together with the recycled benzene, the catalyst complex and the polyalkylbenzenes.

In the alkylator, ethylene is introduced while the reaction mass is maintained at 266°F under a pressure of 4.5 atmospheres. The reaction is exothermic, the temperature being controlled by evaporating benzene to carry off the heat of reaction. The benzene vapors and ethane which pass through unreacted, are vented to a condenser and separator, where most of the benzene is recovered and recycled to the alkylator. The remaining gases are sent to an absorption tower where they are contacted with cold polyalkylbenzenes recycled from the product-rectification stage through a brine cooler. The remaining benzene vapors in the gas are dissolved in the polyalkylbenzenes which pass to the complex-collection tank for recycle to the alkylator. The ethane is sent to another plant for cracking or is used as a fuel.

The liquid reaction mass from the alkylator is sent to a settling tank, where benzene vapor and ethane are vented. It then passes through a cooler to a second settling tank which is also vented. The benzene vapor and ethane from these tanks are sent to the same condenser, separator and absorption column receiving the vented gases from the alkylator. In the second settling tank the catalyst complex separates in a layer at the bottom and is withdrawn. A part of this complex is sent to the complex-collection tank where it is recycled to the alkylator. The remainder of the complex is sent to the dealkylator. The hydrocarbon layer from the settling tank is sent to a separator where remaining gases are vented.

From the separator the hydrocarbons pass to three scrubbing columns in series, where they are first washed with water to remove residual complex, then with caustic to neutralize acid components and finally with water to remove residual alkali. From the final scrubber, the stream passes to a settling tank to remove the water. It is then pumped through a preheater to three rectification columns in series.

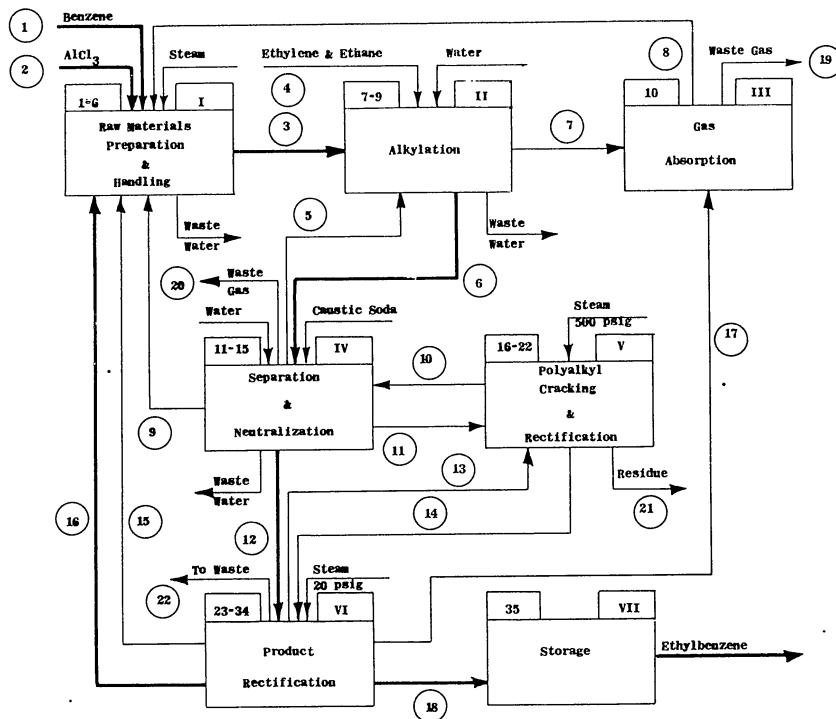
In the first column, benzene, together with any remaining water, is obtained as the overhead product. It is condensed and sent to a separator to remove the water. Ninety percent of the benzene is sent to the complex-collection tank for recycle to the alkylator, while 10% is wasted from the system. In the second column, ethylbenzene and the lighter polyalkylbenzenes are removed as overhead product. They are sent to the third rectification column where ethylbenzene is removed overhead and is condensed and sent to storage. The polyalkylbenzenes, comprising the bottoms, are recycled to the benzene-absorption column. The bottoms from the second rectification column are sent to a polyalkyl still where lighter fractions are removed overhead and recycled to the benzene absorption column. The bottoms are sent to the dealkylator.

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In the dealkylator, the temperature is maintained at 500°F. Here, the polyalkyls are cracked to benzene and alkyls with the formation of some tars. The benzene and alkyls are removed overhead, condensed and recycled to the first of the two settling tanks which receive the liquid reaction mass from the alkylator. The tars are removed from the dealkylator as residue.

The controlling factors in the process are the temperature and pressure of the alkylation step, together with a controlled recycle of polyalkylbenzenes to maintain the desired equilibrium conditions in the alkylator. It is important that practically all moisture be excluded from the reactants in contact with the aluminum chloride and catalyst complex, in order to prevent formation of corrosive products and loss of catalyst through hydrolysis.

FIGURE IV.1  
ETHYLBENZENE  
FRIEDEL-CRAFTS SYNTHESIS



Flow Rates (lb/hr)											
Material	1	2	3	4	5	6	7	8	9	10	11
Benzene	4,898		9,622		213	5,063	213	213			
Aluminum Chloride		60									
Ethylene				1,577							
Ethane				849		124	725				
Catalyst Complex			440			435		111			111
Polyalkyls			832			1,392		832			
Ethylbenzene						5,780					
Regenerated Aromatics										199	
Flow Rates (lb/hr)											
Material	12	13	14	15	16	17	18	19	20	21	22
Benzene	5,063				4,618						445
Ethane								725	124		
Polyalkyls	1,392	1,392	994	162		832					
Ethylbenzene	5,780						5,780				
Residue										310	

NOTE: In the small blocks in the diagram above, Roman numerals refer to Operations in TABLE IV.2; Arabic numerals correspond to Process Equipment Items.

#### PROCESS DATA

Standardized tables containing the results of our study of the Soviet process for the production of ethylbenzene by the Friedel-Crafts synthesis are presented in this section. Tables IV.1-IV.4, which follow, tabulate the process data in terms of input-output quantities.

While the technical details of the process have been drawn from Soviet practice (1-6), the equipment information has been derived primarily from German and US sources (7, 8). Wherever possible, auxiliary-item inputs, such as piping, electricals, maintenance, etc., have been estimated from over-all factors derived from US experience, with appropriate adjustment for Soviet practice. Detailed descriptions of methods of sizing equipment and computing the corresponding values of weights and labor of installation are presented in our Chemical-Process Calculation Manual (8). Where it has been necessary to approximate the input quantities for a special item of equipment, such as a furnace, or to estimate certain over-all factors from US practice, this is indicated by an asterisk (\*) following the item number in the Capital-Items table. In general, calculations of this nature will only be shown in our basic process engineering work sheets.

Process information actually derived from Soviet sources is indicated by reference. We have provided for the estimation of major differences between US and Soviet practice by means of average labor- and weight-conversion factors. Thus, while the majority of the Capital-Items information is expressed on a US basis, the Capital-Summary figures are, for the most part, estimates of actual Soviet practice. The last is also true of the Material-Summary and General-Process-Items information. In general, we have been able to derive reliable estimates of Soviet items falling in CEIR Code Categories 02 (Machinery, Excluding Electrical), 03 (Electrical Machinery, Equipment and Supplies), 06 (Fabricated Metal Products), 07 (Chemicals), 08 (Metals, Primary and Secondary), 18 (Metal Ores and Concentrates), 19 (Non-Metallic Minerals), as well as materials and labor involved in building construction.

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ETHYLBENZENE  
(FRIEDEL-CRAFTS SYNTHESIS)

TABLE IV.1

## CAPITAL SUMMARY

CEIR Code	CEIR Commodity Group	Quantity	Units
0201	Machine Tools	4.50	MT
0209	Pumps and Compressors	0.353	MT
0217	Refrigeration Equipment	0.750	MT
0222	Industrial Machinery, NEC	105.	MT
0225	Replacement Parts for Other 02 Commodities	1.80	MT
0301	Motors and Generators	0.368	MT
0305	Electrical Measurement and Control Apparatus	0.430	MT
0310	Electrical Machinery and Equipment, NEC	23.6	MT
0406	Trucks	1	U
0407	Passenger Cars	1	U
0501	Mechanical Measuring and Control Instruments	0.573	MT
0610	Tanks	5.11	MT
0612	Metal Fabrication for Construction	0.130	TMT
0717	Paints, Varnishes	1.49	MT
0805	Ordinary Steel Finished Shapes	0.108	TMT
0806	Quality Steel Finished Shapes	0.00366	TMT
0808	Iron, Steel Forgings	0.00930	TMT
0809	Iron Castings	0.00533	TMT
0811	Primary Copper	2.46	MT
0813	Primary Zinc	0.930	MT
0826	Non-Ferrous Rolling, Drawing	0.200	CM
0827	Non-Ferrous Casting	0.200	CM
1010	Petroleum Coke Residuals, NEC	0.00352	TMT
1401	Round Timber	0.0149	TCM
1402	Saw-Mill Products	0.0664	TMT
1403	Wood Products	0.00216	TMT
1404	Furniture	1.09	MT

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TABLE IV.1 (Continued)

CEIR Code	CEIR Commodity Group	Quantity	Units
1601	Refractories	0.0169	TMT
1603	Cement	0.143	TMT
1604	Brick and Hollow Tile	0.219	TMT
1605	Gypsum Products	0.00648	TMT
1606	Lime	0.0138	TMT
1608	Flat Glass	1.20	MT
1609	Non-Metallic Construction Materials, NEC	0.332	TMT
1905	Stone, Sand, and Gravel	1.55	TMT
2300	Services (incl. Engineering) (US Basis) <sup>(a)</sup>	0.0111	TMY
2400	Labor (USSR Basis) <sup>(a)</sup>	0.0594	TMY

(a) See Table IV.2, Footnote (d).

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ETHYLBENZENE  
(FRIEDEL-CRAFTS SYNTHESIS)

TABLE IV. 2

## CAPITAL ITEMS

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Operation I - Raw Materials Preparation and Handling</u>				
1	Azeotropic Dryer (1.2 ft diam x 30 ft, 20 plates @ 1.5 ft spacing)	0222	3.85	240
2	Separation Tank (400 gal)	0610	0.14	13
3	Feed Hopper, Aluminum Chloride (60 lb/hr)	0222	0.10	5
4	Tank, Complex Preparation (40 gal, agitated)	0610	0.08	8
5	Pump, Centrifugal (50 gpm @ 500 ft head)	0209 0301	0.15) 0.13)	17
6	Tank, Complex Collection (2000 gal)	0610	0.72	41
<u>Operation II - Alkylation</u>				
7	Alkylator (2; ea 2.5 ft diam x 50 ft, 45 psig design pressure)	0222	9.60	480
8	Condenser (24 sq ft heat-transfer area)	0222	0.04	8
9	Separation Tank (50 gal)	0610	0.30	3
<u>Operation III - Gas Absorption</u>				
10	Absorption Column (2 ft diam x 42 ft)	0222 1601	2.74) 1.29)	180

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TABLE IV. 2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Operation IV - Separation and Neutralization</u>				
11	Separation Tank (2; ea 1700 gal, 100 psig design pressure)	0610	2.72	238
12	Cooler (700 sq ft heat-transfer area)	0222	2.35	110
13	Separation Tank (2000 gal)	0610	0.72	41
14	Scrubbing Column (3; ea 4.5 ft diam x 25 ft)	0222 1601	18.96) 15.57)	720
15	Separation Tank (2; ea 50 gal)	0610	0.60	6
<u>Operation V - Polyalkyl Cracking and Rectification</u>				
16	Dealkylator (4 ft diam x 10 ft, heated with steam coils, 1000 sq ft heat-transfer area)	0222	8.57	470
17	Cooler (50 sq ft heat-transfer area)	0222	0.07	14
18	Separation Tank (5 gal)	0610	Negligible	Negligible
19	Pump, Centrifugal (1 gpm @ 150 ft head)	0209 0301	0.08) 0.05)	10
20	Distillation Column (3 ft diam x 25 ft)	0222	7.62	470
21	Reboiler (26 sq ft heat-transfer area)	0222	0.42	9
22	Condenser (10 sq ft heat-transfer area)	0222	0.02	4

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TABLE IV. 2 (Continued)

Item No.	Process Equipment(a)	CEIR Code	Quantity(b)	Installation Labor (Man-Hr)
<u>Operation VI - Product Rectification</u>				
23	Settling Tank (2000 gal)	0610	0.72	41
24	Pump, Centrifugal (30 gpm @ 100 ft head)	0209 0301	0.08) 0.05)	10
25	Heater (45 sq ft heat-transfer area)	0222	0.03	13
26	Distillation Column (5 ft diam x 75 ft, 50 plates @ 1.5 ft spacing)	0222	50.87	750
27	Condenser (3; ea 100 sq ft heat-transfer area)	0222	0.90	72
28	Separation Tank (1000 gal)	0610	0.37	21
29	Pump, Centrifugal (15 gpm @ 50 ft head)	0209 0301	0.08) 0.05)	10
30	Reboiler (26 sq ft heat-transfer area)	0222	0.42	9
31	Distillation Column (2, ea 2.5 ft diam x 90 ft, 60 plates @ 1.5 ft spacing)	0222	30.16	940
32	Reboiler (1, 24.2 sq ft heat-transfer area - 1, 22 sq ft heat-transfer area)	0222	0.79	16
33	Settling Tank (1000)	0610	0.44	25
34	Pump Centrifugal (3 gpm @ 100 ft head)	0209 0301	0.08) 0.05)	10

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TABLE IV. 2 (Continued)

Item No.	Process Equipment(a)	CEIR Code	Quantity(b)	Installation Labor (Man-Hr)
<u>Operation VII - Storage</u>				
35	Storage Tank (200,000 gal)	0612 0805	(23.0) 23.0)	1,010
Total Weight of Process Equipment (exclusive of CEIR Code 0612)			184.98 MT	
Total Labor for Installation of Process Equipment				6,014
<u>Auxiliary Items</u>				
36	Improved Land			4,110
37	Ventilation:			
	Stack (60 ft)	0222	0.63)	
	Ducts (28 in. sq x 200 ft)	0612	(0.69)	
		0805	0.69)	
	Fans and Blowers (2; ea 8000 SCFM @ 3 in. H <sub>2</sub> O head)	0222 0301	2.46) 0.16)	301
38	Refrigeration System	0217	1.00	240
39	Pipe, Valves and Fittings:			
	Metal Fabrication for Construction	0612	(88.0 )	
	Ordinary Steel Finished Shapes	0805	59.0 )	
	Quality Steel Finished Shapes	0806	4.88)	
	Iron, Steel Forgings	0808	12.4 )	
	Iron Castings	0809	7.11)	
	Primary Copper	0811	3.28)	
	Primary Zinc	0813	1.24)	
				STAT

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TABLE IV.2 (Continued)

Item No.	Process Equipment (a)	CEIR Code	Quantity (b)	Installation Labor (Man-Hr)
<u>Auxiliary Items (Continued)</u>				
	Pipe, Valves and Fittings: (Cont'd)			
	Non-Ferrous Rolling, Drawing	0826	( 0.266 ) (CM)	
	Non-Ferrous Casting	0827	( 0.266 ) (CM)	
	Non-Metallic Construction Material, NEC	1609	0.799)	12,300
40	Foundations for Equipment:			
	Reinforcing Rod	0612	(19.0 )	
	Cement	0805	18.0 )	
	Sand, Stone, and Gravel	1603	50.0 )	
		1905	450.0 )	2,200
41	Paint	0717	1.99	1,850
	Insulation for Equipment and Piping	1609	4.63	2,051
42	Structural Steel for Equipment	0612	(14.9 )	
		0805	14.9 )	812
43	Electricals (Motors less than 5 hp and miscellaneous electrical supplies)	0310	31.5	5,260
44	Instruments	0305	( 0.573	
		0501	0.573)	821
45	Maintenance:			
	Machine Tools	0201	( 6.0	
	Replacement Parts for Other 02 Commodities	0225	2.40 )	1,500
46	Buildings (8000 sq ft floor area)(c)			
	Ordinary Steel Finished Shapes	0612	(21.0 )	
		0805	21.0 )	
	Petroleum Coke Residuals, NEC	1010	3.52 )	
	Round Timber	1401	14.9 ) (CM)	

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TABLE IV.2 (Continued)

Item No.	Process Equipment(a)	CEIR Code	Quantity(b)	Installation Labor (Man-Hr)
<u>Auxiliary Items (Continued)</u>				
	Buildings (Cont'd)			
	Saw-Mill Products	1402	66.4 )	
	Wood Products	1403	2.16)	
	Cement	1603	92.8 )	
	Brick, Hollow Tile	1604	219. )	
	Gypsum Products	1605	6.48)	
	Lime	1606	13.8 )	
	Flat Glass	1608	1.20)	
	Non-Metallic Construction Material, NEC	1609	327. )	
	Sand, Stone, and Gravel	1905	1,100. )	
	Office Furniture	1404	1.09)	39,400
47	Plant Transportation:			
	Truck	0406	1 (U)	
	Passenger Car	0407	1 (U)	
48	Services (Includes Engineering)	2300		26,700
<u>Installation Labor Summary(d)</u>				
	USSR Basis	2400		39,400
	US Basis	2400		(37,500)
	US Normalized to USSR Basis	2400		103,100
	Total Installation Labor USSR Basis	2400		142,500

STAT

TABLE IV. 2 (Continued)

## NOTES

- (a) Material of construction is mild steel unless otherwise specified. All equipment-weight and labor-of-installation data are US basis unless otherwise specified. A factor of 0.75 is used to convert the weight of metallic items in this table to the USSR basis presented in the Capital-Summary table (8).
- (b) Metric tons (MT) unless otherwise noted.
- (c) Data are USSR basis except for the estimated floor area.
- (d) Installation labor under Buildings is based on USSR practice; all other installation labor is based on US practice. The installation labor reported for CEIR Code 2400 in the Capital-Summary table is on a USSR basis, US labor being converted to USSR labor by applying a normalizing factor of 2.75 (8). Labor under CEIR Code 2300 is on a US basis in all tables.

ETHYLBENZENE  
(FRIEDEL-CRAFTS SYNTHESIS)

TABLE IV. 3

## MATERIAL SUMMARY

## Material Input

Material	Input/30 days Quantity	Units	CEIR Code	Specification
Benzene	1,600	MT	0714	Dry, thiophene-free
Olefins	782	MT	0714	Pure, dry gas (65.0% ethylene, 35.0% ethane)
Aluminum Chloride	0.0196	TMT	0711	Anhydrous powder
Caustic Soda	47.0	MT	0706	(100% NaOH basis)
Maintenance	1.24	MT	0225	Replacement parts

## Material Output

Material	Output/30 days Quantity	Units	CEIR Code	Specification
Ethylbenzene	1,887	MT	0714	Pure

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ETHYLBENZENE  
(FRIEDEL-CRAFTS SYNTHESIS)

TABLE IV. 4

GENERAL PROCESS ITEMS

Rated Annual Capacity	18,870	MT <sup>(a)</sup>
Percent of rated annual capacity realizable:		
1st year	75	%
2nd year	85	%
3rd year	95	%
4th year	98	%
Maximum Realizable Short Term Capacity	103	%
Labor Input to Process <sup>(b)</sup>		
US Basis	156,000	Man-Hr/Yr
USSR Basis	468,000	Man-Hr/Yr (8)
Labor Scale Factor	0.7 <sup>(c)</sup>	
Range of applicability of scale factor:		
Lower limit	0.2 <sup>(d)</sup>	
Upper limit	2.0 <sup>(d)</sup>	
Electrical Input Per Year	675,000	KWH
Water Input Per Year	138,000	MT
Net Fuel Input Per Year (as steam)	184,000	MM BTU
Process Heat Other Than Steam	-	MM BTU
Time Required to Build New Plant	12	Months

(a) Based on 300 days per year operation at 100% mechanical efficiency.

(b) Assumes a non-automated plant.

(c) Exponential factor for rated annual plant capacity.

(d) Multiplicative factor for rated annual plant capacity.

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SECTION V

STYRENE  
(ETHYLBENZENE-DEHYDROGENATION PROCESS)

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#### INTRODUCTION

Barg (1) summarized the methods for production of styrene and stated that in the basic industrial process ethylbenzene was dehydrogenated catalytically. Yukelson (2) described this process in moderate detail; other Soviet authors (3, 4) discussed the process too briefly to be of value to us. Gorin (5) indicated that the USSR considers increased production of styrene important, and that catalysts which double or triple production rates have been developed.

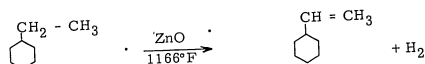
Our original estimate of a Soviet plant capacity was approximately 5000 metric tons per year, which would be sufficient to produce 15,000 metric tons per year of "SKS" rubber. According to Nekrasov (6), this would be the largest new synthetic-rubber capacity which the Soviets would install. It was observed, however, that the distillation column of the styrene system described by Yukelson (2) was nearly identical in size with a unit which operated at Schkopau, near Leipzig, Germany, in World War II (7). The Schkopau plant produced 1,700 metric tons per month of styrene, and it appeared reasonable to use this capacity for a Soviet operation, presumably corresponding to 17-20,000 metric tons per year. This production is enough to meet the needs of the Kuskovo Chemical Plant, which manufactures polystyrene (8), and a synthetic rubber plant.

A styrene plant can be considered fairly readily adaptable to production of related chemicals such as  $\alpha$ -methylstyrene or halogenated styrenes.

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PROCESS DESCRIPTION

The manufacture of styrene by the dehydrogenation of ethylbenzene is based on the following reaction:



Since the reaction is endothermic and a volume increase accompanies dehydrogenation, high temperature and decreased pressure favor the formation of styrene. There is, however, an optimum temperature range of 1112 to 1220°F for production of styrene, since side reactions producing benzene and toluene take place due to the thermal decomposition of ethylbenzene and styrene. At temperatures above 1220°F, these side reactions are favored, resulting in excess benzene and toluene formation and a resultant decrease in the yield of styrene. Rather than run this high-temperature process under vacuum, in order to produce the lower pressure which favors dehydrogenation, steam is used to reduce the partial pressure of the reaction products to 0.1 atmosphere. This reduction of pressure increases the conversion of ethylbenzene from 25-30% to 70-80%.

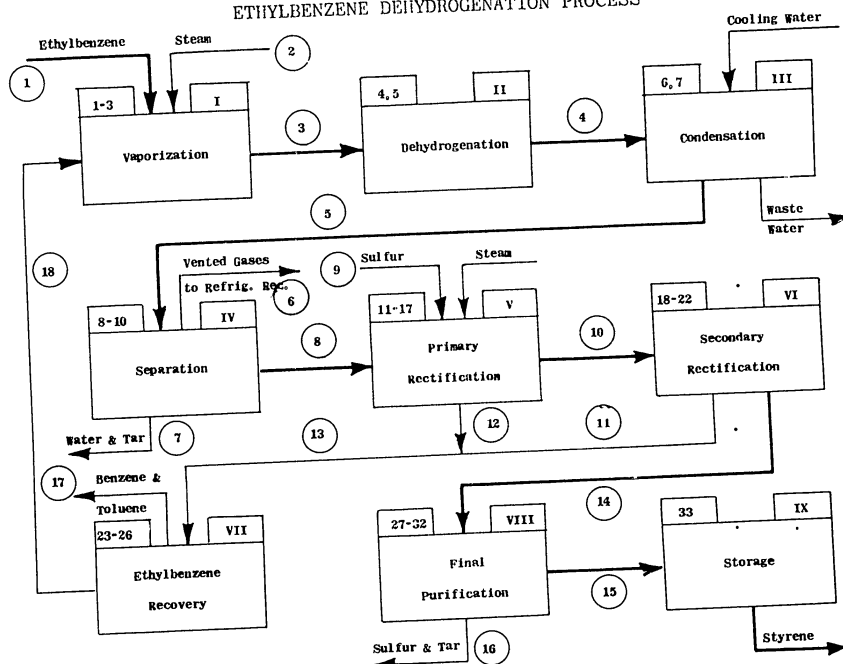
The raw material for styrene production is ethylbenzene, which is usually obtained from production facilities adjacent to the styrene plant. The catalyst for dehydrogenation is composed of 85% zinc oxide, 5% calcium oxide, 2% potassium hydroxide, 3% potassium chromate and 5% potassium sulfate.

Ethylbenzene is pumped to a vaporizing tank where steam is introduced to volatilize it. The vapors (at 320°F) are passed through a heat exchanger, where heat is received from the reaction products and the vapor temperature is raised to 968°F. The vapors are then mixed with 1310°F steam from a superheating furnace and sent to the dehydrogenation reactor at a temperature of 1166°F. The steam sent to the superheating furnace is preheated to approximately 725°F in a heat exchanger, where additional heat is transferred from the reaction products downstream of the ethylbenzene heat exchanger.

The products from the reactor (at 1020°F) pass through the two heat exchangers into a spray desuperheater, where they are contacted

FIGURE V. 1.

FIGURE V. 1  
STYRENE  
ETHYLBENZENE DEHYDROGENATION PROCESS



Flow Rates (lb/hr)								
Material	1	2	3	4	5	6	7	8
Ethylbenzene	5,780		14,662	8,882	8,882			8,882
Steam		38,120	38,120	38,120				
Hydrogen				103.7	103.7	103.7		
Styrene				5,385	5,385			5,385
Water					38,120		38,120	
Sulfur								30
Benzene				87.4	87.4			87.4
Toluene				145.6	145.6			145.6
Tar				58.3	58.3		58.3	

Flow Rates (lb/hr)								
Material	10	11	12	13	14	15	16	17
Ethylbenzene	1,345	1,345	7,537	8,882				8,882
Styrene	5,385				5,295	5,200		
Sulfur	30							
Benzene	2.4	2.4	85.0	87.4				87.4
Toluene	5.6	5.6	140.0	145.6				145.6
Residue					120		215	

NOTE: In the small blocks in the diagram above, Roman numerals refer to operations in TABLE VII. 2; Arabic numerals correspond to Process Equipment Items.

with water sprays which cool the gases and remove some of the tars formed during reaction. The aqueous effluent goes to a separator where tars are removed, after which the water is sent to waste. The gases from the desuperheater (at 221°F) are sent to a water-cooled condenser from which they pass to a gravity separator, where non-condensable gases are vented to a refrigeration system for recovery. Overflow from the gravity separator is sent to a second separator, where water is removed and sent to the spray desuperheater. From the separator the product is sent first to a settling tank where more of the tars are removed and then to a collection tank. At this point, the crude product contains approximately 37% styrene, 61% ethylbenzene, 1% toluene, 0.6% benzene and 0.4% tars.

The crude styrene is mixed with sulfur to inhibit polymerization and is sent to the primary rectification column. The overhead product, composed of benzene, ethylbenzene, toluene and a small amount of styrene, is cooled and sent to a separator where the styrene and condensed ethylbenzene are removed from the benzene, ethylbenzene and toluene vapors. A portion of the condensate is recycled to the rectifying column, while the remainder is recycled for further dehydrogenation.

The bottoms, containing 80% styrene, 20% ethylbenzene, some benzene and toluene, are sent to the secondary rectification column. The overhead product, composed of benzene, ethylbenzene, toluene and styrene, is cooled and sent to a separator, where condensed ethylbenzene and styrene are removed. A portion of this condensate (containing approximately 40% styrene and 60% ethylbenzene) is recycled to the secondary rectification column, while the remainder is recycled to the feed to the primary rectification column.

The overhead gases from the primary and secondary rectification steps are sent through a brine cooler, condensed and fed to the benzene-toluene still. The overhead product containing pure benzene and toluene is cooled and sent to storage. The bottoms, which are composed mainly of ethylbenzene, are recycled for conversion.

The bottoms from the secondary rectification column are sent to the finishing still, where styrene is distilled off, cooled and sent to storage. The residual tars in the still bottoms are removed and burned.

The controlling factors in the process are the temperature and partial pressure of the reaction products during dehydrogenation and the age of the catalyst. Product rectification must be carefully controlled to prevent polymerization and maximize the yield of styrene monomer.

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PROCESS DATA

Standardized tables containing the results of our study of the Soviet process for the production of styrene by the ethylbenzene dehydrogenation process are presented in this section. Tables V.1-V.4, which follow, tabulate the process data in terms of input-output quantities.

While the technical details of the process have been drawn from Soviet practice (1-4), the equipment information has been derived primarily from US sources (7, 9). Wherever possible, auxiliary-item inputs, such as piping, electricals, maintenance, etc., have been estimated from overall factors derived from US experience, with appropriate adjustment for Soviet practice. Detailed descriptions of methods of sizing equipment and computing the corresponding values of weights and labor of installation are presented in our Chemical-Process Calculation Manual (9). Where it has been necessary to approximate the input quantities for a special item of equipment such as a furnace, or to estimate certain overall factors from US practice, this is indicated by an asterisk (\*) following the item number in the Capital-Items table. In general, calculations of this nature will only be shown in our basic process engineering work sheets.

Process information actually derived from Soviet sources is indicated by reference. We have provided for the estimation of major differences between US and Soviet practice by means of average labor- and weight-conversion factors. Thus, while the majority of the Capital-Items information is expressed on a US basis, the Capital-Summary figures are, for the most part, estimates of actual Soviet practice. The last is also true of the Material-Summary and General-Process-Items information. In general, we have been able to derive reliable estimates of Soviet items falling in CEIR Code Categories 02 (Machinery, Excluding Electrical), 03 (Electrical Machinery, Equipment & Supplies), 06 (Fabricated Metal Products), 07 (Chemicals), 08 (Metals, Primary & Secondary), 18 (Metal Ores & Concentrates), 19 (Non-metallic Minerals), as well as materials and labor involved in building construction.

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STYRENE(ETHYLBENZENE-DEHYDROGENATION PROCESS)TABLE V.1CAPITAL SUMMARY

CEIR Code	CEIR Commodity Group	Quantity	Units
0201	Machine Tools	4.50	MT
0209	Pumps and Compressors	0.443	MT
0217	Refrigeration Equipment	1.875	MT
0222	Industrial Machinery, NEC	95.7	MT
0225	Replacement Parts for Other 02 Commodities	2.35	MT
0301	Motors and Generators	0.278	MT
0305	Electrical Measurement and Control Apparatus	1.22	MT
0310	Electrical Machinery and Equipment, NEC	33.2	MT
0406	Trucks	1	U
0407	Passenger Cars	1	U
0501	Mechanical Measuring and Control Instruments	1.61	MT
0603	Heating and Cooking Apparatus (Small Boilers)	0.00135	TMT
0610	Tanks	2.35	MT
0612	Metal Fabrication for Construction	0.185	TMT
0711	Inorganics, NEC	0.0172	TMT
0717	Paints, Varnishes	2.81	MT
0805	Ordinary Steel Finished Shapes	0.155	TMT
0806	Quality Steel Finished Shapes	0.00516	TMT
0808	Iron, Steel Forgings	0.0131	TMT
0809	Iron Castings	0.00750	TMT
0811	Primary Copper	3.47	MT
0813	Primary Zinc	1.31	MT
0826	Non-Ferrous Rolling, Drawing	0.281	CM
0827	Non-Ferrous Casting	0.281	CM
1010	Petroleum Coke Residuals, NEC	STAT 0.00502	TMT

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TABLE V.1 (Continued)

CEIR Code	CEIR Commodity Group	Quantity	Units
1401	Round Timber	0.0212	TCM
1402	Saw-Mill Products	0.0946	TMT
1403	Wood Products	0.00308	TMT
1404	Furniture	1.09	MT
1601	Refractories	0.0710	TMT
1603	Cement	0.0206	TMT
1604	Brick and Hollow Tile	0.0312	TMT
1605	Gypsum Products	0.00923	TMT
1606	Lime	0.0196	TMT
1608	Flat Glass	1.71	MT
1609	Non-Metallic Construction Materials, NEC	0.474	TMT
1905	Stone, Sand, and Gravel	2.18	TMT
2300	Services (Incl. Engineering)(US Basis) <sup>(a)</sup>	0.0148	TMY
2400	Labor (USSR Basis) <sup>(a)</sup>	0.0807	TMY

<sup>(a)</sup>See Table VII.2, Footnote (d).

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## STYRENE

## (ETHYLBENZENE-DEHYDROGENATION PROCESS)

TABLE V.2

## CAPITAL ITEMS

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hrs)
<u>Operation I - Vaporization</u>				
1	Blower (2000 SCFM @ 3 in H <sub>2</sub> O head)	0222	0.20	
		0301	0.03	14
2	Furnace, Dutch Oven (2550 cu ft, fire brick)	1601	56.0	520
3	Vaporizer (25 sq ft heat-transfer area, steam heated)	0603	0.4	8
<u>Operation II - Dehydrogenation</u>				
4(*)	Reactor, Shaft Type (240 cu ft, copper with 2 layers of brick insulation, filled with catalyst held in-place by weighted ram)	0222	3.5 )	
		0711	17.2 )	
		1601	15.0 )	200
5	Heat Exchanger (2; 1 @ 45 sq ft heat-transfer area - 1 @ 10 sq ft heat-transfer area)	0222	0.25	17
<u>Operation III - Condensation</u>				
6(*)	Spray Desuper heater (4 ft diam x 30 ft)	0222	0.75	70
7	Condenser (450 sq ft heat-transfer area)	0222	0.7	80

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TABLE V. 2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hrs)
<u>Operation IV - Separation</u>				
8	Separation Tank (1;2000 gal - 1;1600 gal - 1,1000 gal - 1;600 gal)	0610	2.1	118
9	Storage Tank, Crude Styrene (47,000 gal)	0612 0805	(9.0) 9.0)	480
10	Pump, Centrifugal (2; ea 35 gpm @ 500 ft)	0209 0301	0.35) 0.19)	30
<u>Operation V - Primary Rectification</u>				
11	Pre-heater (13 sq ft heat-transfer area, steam heated)	0603	0.34	5
12	Mixing Tank (500 gal, propeller agitated)	0610	0.69	24
13	Rectification Column (6 ft diam x 60 ft, 28.35 in. Hg vacuum at top of column provided by steam jet)	0222	62.31	750
14	Reboiler (18 sq ft heat-transfer area, steam heated)	0603	0.37	6
15	Cooler (350 sq ft heat-transfer area)	0222	0.8	85
16	Tank (500 gal)	0610	0.23	13
17	Pump, Centrifugal (15 gpm @ 100 ft head)	0209 0301	0.08) 0.05)	10
<u>Operation VI - Secondary Rectification</u>				
18	Rectification Column (5 ft diam x 40 ft; 28.35 in. Hg vacuum at top of column provided by steam jet)	0222	28.22	750

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TABLE V. 2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hrs)
<u>Operation VI - Secondary Rectification (Continued)</u>				
19	Reboiler (18 sq ft heat-transfer area, steam heated)	0603	0.37	6
20	Cooler (150 sq ft heat-transfer area)	0222	0.4	33
21	Tank (220 gal)	0610	0.09	7
22	Pump, Centrifugal (15 gpm @ 100 ft head)	0209 0301	0.08) 0.05)	10
<u>Operation VII - Ethylbenzene Recovery</u>				
23	Condenser (10 sq ft heat-transfer area, brine-cooled)	0222	0.022	4
24	Distillation Column (4 ft diam x 35 ft)	0222	17.73	470
25	Reboiler (10 sq ft heat-transfer area, steam-heated)	0603	0.32	4
26	Cooler (27 sq ft heat-transfer area)	0222	0.13	9
<u>Operation VIII - Final Purification</u>				
27	Distillation Column (4 ft diam x 20 ft)	0222	11.35	470
28	Reboiler (18 sq ft heat-transfer area, steam heated)	0222	0.37	6
29	Cooler (350 sq ft heat-transfer area)	0222	0.8	85
30	Tank (50 gal)	0610	0.024	3
31	Condenser (5 sq ft heat-transfer area, brine-cooled)	0222	0.014	2
32	Pump, Centrifugal (15 gpm @ 100 ft head)	0209 0301	0.08) 0.05)	10

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TABLE V.2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hrs)
<u>Operation IX - Storage</u>				
33	Storage Tanks (2; ea 100,000 gal)	0612 0805	(30) 30	1440
Total Weight of Process Equipment (exclusive of CEIR Code 0612)			260.64MT	
Total Labor for Installation of Process Equipment				5,739
<u>Auxiliary Items</u>				
34	Improved Land			5,790
35	Refrigeration System	0217	2.50	540
36	Pipe, Valves and Fittings:			
	Metal Fabrication for Construction	0612	(124. )	
	Ordinary Steel Finished Shapes	0805	83.2 )	
	Quality Steel Finished Shapes	0806	6.88 )	
	Iron, Steel Forgings	0808	17.5 )	
	Iron Castings	0809	10.0 )	
	Primary Copper	0811	4.63 )	
	Primary Zinc	0813	1.75 )	
	Non-Ferrous Rolling, Drawing	0826	(0.375)(CM)	
	Non-Ferrous Casting	0827	(0.375)(CM)	
	Non-Metallic Construction Material, NEC	1609	1.13	17,400
37	Foundations for Equipment:			
	Reinforcing Rod	0612 0805	(30.0 ) 30.0 )	
	Cement	1603	74.0 )	
	Sand, Stone, and Gravel	1905	620. )	3,250

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TABLE V.2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hrs)
<u>Auxiliary Items (Continued)</u>				
38	Paint	0717	2.81	2,610
39	Insulation for Equipment and Piping	1609	6.52	2,890
40	Structural Steel for Equipment	0612 0805	14.2 ) 14.2 )	775
41	Electrical (Motors less than 5 hp and miscellaneous electrical supplies)	0310	44.3	7,400
42	Instruments	0305	1.62)	
43	Maintenance:	0501	1.61)	2,310
	Machine Tools	0201	6.0	1,500
	Replacement Parts for Other 02 Commodities	0225	3.13	
44	Buildings (11,400 sq ft floor area) <sup>(c)</sup>			
	Ordinary Steel Finished Shapes	0612 0805	(29.9 ) 29.9 )	
	Petroleum Coke Residuals, NEC	1010	5.02)	
	Round Timber	1401	21.2 )(CM)	
	Saw-Mill Products	1402	94.6	
	Wood Products	1403	3.08	
	Cement	1603	132.	
	Brick, Hollow Tile	1604	312.	
	Gypsum Products	1605	9.23	
	Lime	1606	19.6	
	Flat Glass	1608	1.71	
	Non-Metallic Construction Material, NEC	1609	466.	
	Sand, Stone, and Gravel	1905	1,560.	
	Office Furniture	1404	1.09	56,200

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TABLE V.2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Auxiliary Items (Continued)</u>				
45	Plant Transportation:			
	Truck	0406	1 (U)	
	Passenger Car	0407	1 (U)	
46	Services (Includes Engineering)	2300		35,500
<u>Installation Labor Summary<sup>(d)</sup></u>				
	USSR Basis	2400		56,200
	US Basis	2400		(50,000)
	US Normalized to USSR Basis	2400		137,500
	Total Installation Labor USSR Basis	2400		193,700

(a) Material of construction is mild steel unless otherwise specified. All equipment-weight and labor-of-installation data are US basis unless otherwise specified. A factor of 0.75 is used to convert the weight of metallic items in this table to the USSR basis presented in the Capital Summary table (9).

(b) Metric tons (MT) unless otherwise noted.

(c) Data are USSR basis except for the estimated floor area.

(d) Installation labor under Buildings is based on USSR practice; all other installation labor is based on US practice. The installation labor reported for CEIR Code 2400 in the Capital Summary table is on a USSR basis, US labor being converted to USSR labor by applying a normalizing factor of 2.75 (9). Labor under CEIR Code 2300 is on a US basis in all tables.

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## STYRENE

## (ETHYLBENZENE-DEHYDROGENATION PROCESS)

TABLE V.3

## MATERIAL SUMMARY

Material	Material Input		CEIR Code	Specification
	Quantity	Units		
Ethylbenzene	1,890.	MT	0714	Pure
Sulfur	0.00978	TMT	1909	Ground, 99.8% S
Catalyst	0.00172	TMT	0711	(85% ZnO, 5% CaO, 5% K <sub>2</sub> SO <sub>4</sub> , 3% K <sub>2</sub> CrO <sub>4</sub> , 2% KOH)
Maintenance Supplies	1.56	MT	0225	Replacement parts

## Material Output

Material	Output/30 Days <sup>(a)</sup>		CEIR Code	Specification
	Quantity	Units		
Styrene	1,700	MT	0714	Pure monomer
Mixed Aromatics	76.1	MT	0714	62.5% Toluene, 37.5% Benzene

(a) Operating days.

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## STYRENE

## ETHYLBENZENE-DEHYDROGENATION PROCESS

TABLE V.4

## GENERAL PROCESS ITEMS

Plant Production		MT <sup>(a)</sup>
Rated Annual Capacity	17,000	
Percent of rated annual capacity realizable:		
1st year	75	%
2nd year	85	%
3rd year	95	%
4th year	98	%
Maximum Realizable Short-Term Capacity	103	%
Annual Labor Input to Process <sup>(b)</sup>		
US Basis	150,000	Man/Hr
USSR Basis	450,000	Man/Hr (9)
Labor Scale Factor	0.7 <sup>(c)</sup>	
Range of Applicability of Scale Factor:		
Lower limit	0.2 <sup>(d)</sup>	
Upper limit	2.0 <sup>(d)</sup>	
Annual Electrical Energy Input	675,000	KWH
Annual Water Input	8,500,000	MT
Net Annual Process Heat Input		
In the form of steam <sup>(e)</sup>	308,000	MM BTU
Other than steam <sup>(f)</sup>	5	MM BTU
Time Required to Build New Plant	12	

(a) Based on 300 days per year operation at 100% mechanical efficiency.

(b) Assumes a non-automated plant.

(c) Exponential factor for rated annual plant capacity.

(d) Multiplicative factor for rated annual plant capacity.

(e) Expressed as the heat content of the steam.

(f) Expressed as the energy content of the fuel.

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SECTION VI

ISOPROPYLBENZENE  
(FRIEDEL-CRAFTS SYNTHESIS)

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### INTRODUCTION

Several Soviet publications dealing with the manufacture, properties, and uses of isopropylbenzene (cumene) were located in our literature search (1, 2, 3, 4, 5). The books by Dalin et al (4) and Yukelson (2) provided the basic information for our plant design.

Dalin et al (4) discussed all of the processes for alkylating benzene, and mentioned (4, p. 87) that the Sumgait plant used aluminum chloride catalyst. Yukelson (2) gave a material balance for this process. Kruzalov and Sergeev (6) stated that vapor phase alkylation over phosphoric acid catalyst is also used in the USSR, but no details were given.

The brief description of the Grozny plant contained in the report of the visit of the US Plastics Industry exchange delegation to the USSR in 1958 was also very helpful to us (7, pp. 20-21). This plant produces isopropylbenzene and processes it to phenol and acetone. The dimensions of some important plant equipment and some process information were given as well as the area of the plant site and size of the labor force.

Isopropylbenzene is used not only for the production of phenol and acetone but also for  $\alpha$ -methylstyrene, which is an ingredient in Soviet "SKMS" synthetic rubber. Gorin (8) indicated that increased attention is being given to manufacture of  $\alpha$ -methylstyrene. A minor amount of isopropylbenzene would probably be used for the manufacture of cumene peroxide.

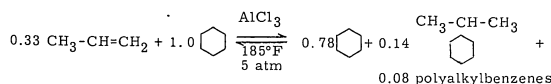
The plant design in this report conforms in size to the Grozny complex (7), i.e., 38,000 metric tons per year; no allowance was made for uses of isopropylbenzene other than for production of phenol and acetone. It is reasonable to anticipate that a unit for dehydrogenation of isopropylbenzene would be added to the combine if the need for  $\alpha$ -methylstyrene warranted it.

The Grozny plant could no doubt be adapted to the production of ethylbenzene, but would be unable to process this chemical to styrene.

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### PROCESS DESCRIPTION

The manufacture of isopropylbenzene (cumene), using the Friedel-Crafts method of synthesis, is based on the following reaction:



The above equation represents the approximate equilibrium conditions within the reactor for the temperature and pressure indicated. Under these conditions, 22% of the benzene reacts on a mol basis, of which 14% forms monoisopropylbenzene and 8% polyalkylbenzenes. To maintain this equilibrium within the reactor and to insure the over-all production of monoisopropylbenzene from the benzene and propylene input to the process, the polyalkylbenzenes and the unreacted benzene are separated from the product and recycled to the reactor.

The raw materials for isopropylbenzene production are benzene, propylene and aluminum chloride. The benzene, which has been purified to remove sulfur compounds, such as thiophene and carbon disulfide, is obtained as a by-product from coke-oven gas or from petroleum refining. The propylene is obtained as a by-product gas stream from petroleum refining. The gas stream, as received, has a composition of approximately 40% propylene, 56% propane, 1% ethane, 0.2% butylene, and 1.8% butane. The presence of ethylene and butylene in the gas stream produces side reactions during alkylation with the formation of ethylbenzene and butylbenzene. Aluminum chloride catalyzes the reaction and is recycled as a catalyst complex. A small amount of moisture-free aluminum chloride must continuously be added to make up for losses in the process.

The raw benzene enters the plant through a wet-benzene collection tank from which it is pumped to a distillation column for drying. Water is removed in the overhead product as a benzene-water azeotrope that is condensed and settled. The benzene layer is recycled to the drying column, while the water is discarded. The dried benzene is removed from the bottom of the column and passed through a product-to-feed heat exchanger into a dry-benzene collection tank. Recycled polyalkylbenzenes, containing some dry benzene removed from the off gases, enter a mixing tank where

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make-up aluminum chloride is added with a very small amount of water to form the make-up catalyst complex. The function of the water is to hydrolyze a little of the aluminum chloride to produce hydrogen chloride, which acts as a catalytic promotor. The catalyst complex has a specific gravity greater than one and is practically insoluble in the hydrocarbons present. The make-up catalyst complex and polyalkylbenzenes are then sent to the alkylation column where dry benzene and the olefin gas stream are introduced.

In the alkylator, the reaction mass is maintained at 185°F under a pressure of 5 atmospheres. The reaction is exothermic, the temperature being controlled by evaporating benzene to carry off some of the heat of reaction and by heat transfer to cooling water in the alkylator jacket.

The benzene vapors and the saturated hydrocarbon gases, which pass through unreacted, are vented to a condenser and separator where most of the benzene is recovered and recycled to the alkylator. The remaining gases are sent to an absorption tower where they are contacted with cold polyalkylbenzenes that have been recycled from product rectification through a brine cooler. The remaining benzene vapors in the gas are dissolved in the polyalkylbenzenes, which become saturated with propane. The polyalkylbenzenes are then sent to a depropanizing column where propane and some benzene are removed overhead and pass through a condenser and separator. Benzene condenses and is recycled to the column. Propane gas is vented and passes to a wash tower. The bottoms from the column, polyalkylbenzenes and benzene, are sent to catalyst make-up for recycle to the alkylator.

The gases from the absorption column are sent to a neutralization column where they are scrubbed with caustic solution. From the neutralization column, they are sent to a wash tower where they are mixed with the gas from the depropanizing column and scrubbed with water. The liquid from the neutralization column and the wash tower passes to a distillation column, where hydrocarbons are removed overhead, combined with the gases from the wash tower, and sent to another plant for pyrolysis. The liquid effluent from the distillation column is sent to waste.

The liquid reaction mass from the alkylator is sent to a settling tank where the catalyst complex settles in a layer at the bottom, and is withdrawn and recycled to the alkylator. The hydrocarbon layer is sent to a second depropanizing column where some benzene and propane are removed overhead and pass through a condenser and separator. The

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benzene condenses and is recycled to the column. Propane gas is vented and passes to the wash tower where it is combined with the other hydrocarbon gases from the process.

The alkylate is removed from the bottom of the second depropanizing column, cooled and sent to a collection tank. The alkylate is next mixed with water in an agitated vessel to hydrolyze any dissolved catalyst complex; the mixture then passes to a settling tank. Water is removed from the bottom of the tank and passed through a benzene trap to waste. The alkylate is sent through a diffusion mixer, together with caustic solution, to a second settling tank. The wash solution is removed at the bottom and passes through the benzene trap to waste. The alkylate is washed with water in a packed column to remove any residual caustic. Water is removed in two final settling tanks and discarded.

The washed alkylate is next sent to rectification in a five-column aggregate. It contains approximately 50% benzene, 30% monoisopropylbenzene, 16% polyisopropylbenzenes, a small amount of ethylbenzene and butylbenzenes, and 0.2% dissolved water. In the first column, benzene and water are removed overhead, condensed and separated. The water is sent to waste. Part of the benzene is recycled to the column and the remainder is sent to the wet-benzene collection tank for drying and is recycled to the alkylator. The bottoms are sent to a second rectification column where ethylbenzene, butylbenzenes and isopropylbenzene are removed overhead. The bottoms are sent to a third column where polyalkylbenzenes are removed overhead and condensed. Part of the polyalkylbenzenes are recycled to this column. The rest are sent first through a brine cooler, then to the benzene-absorption tower and the depropanizing column to catalyst make-up, and are finally recycled to the alkylator. The bottoms from this column are resins which are removed and burned as fuel.

The overhead from the second column is condensed and a part of the condensate is recycled to the column. The major portion is sent to a fourth column, where ethylbenzene is removed overhead, condensed and stored as a by-product. The bottoms are sent to a fifth rectification column where product isopropylbenzene is removed overhead and sent to storage. The bottoms, containing butylbenzenes, are removed and stored as a by-product.

The controlling factors in the process are the temperature and the pressure of the alkylation step and a controlled recycle of polyalkylbenzenes to maintain the desired equilibrium conditions in the alkylator. It is important that the content of four-carbon olefins in the input gas stream be kept as low as possible to prevent an increased  $\text{C}_4\text{H}_8/\text{C}_3\text{H}_6$  benzene due to formation of butylalkylates.

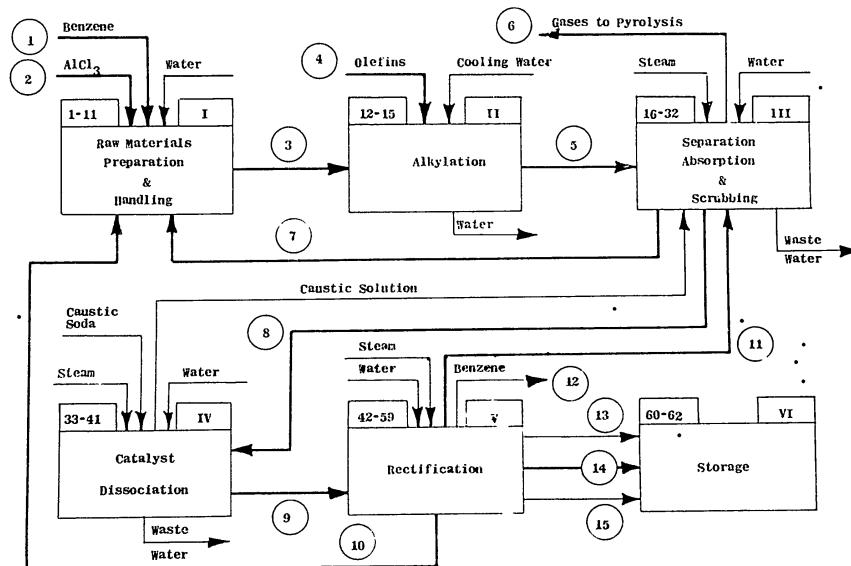
#### PROCESS DATA

Standardized tables containing the results of our study of the Soviet process for the production of isopropylbenzene (cumene) by the Friedel-Crafts synthesis are presented in this section. Tables VI.1 - VI.4, which follow, tabulate the process data in terms of input-output quantities.

While the technical details of the process have been drawn from Soviet practice (1-6,8), the equipment information has been derived primarily from US sources (9). Wherever possible, auxiliary-item inputs, such as piping, electricals, maintenance, etc., have been estimated from over-all factors derived from US experience, with appropriate adjustment for Soviet practice. Detailed descriptions of methods of sizing equipment and computing the corresponding values of weights and labor of installation are presented in our Chemical-Process Calculation Manual (9). Where it has been necessary to approximate the input quantities for a special item of equipment such as furnace, or to estimate certain over-all factors from US practice, this is indicated by an asterisk (\*) following the item number in the Capital-Items table. In general, calculations of this nature will only be shown in our basic process engineering worksheets.

Process information actually derived from Soviet sources is indicated by reference. We have provided for the estimation of major differences between US and Soviet practice by means of average labor- and weight-conversion factors. Thus, while the majority of the Capital-Items information is expressed on a US basis, the Capital-Summary figures are, for the most part, estimates of actual Soviet practice. The last is also true of the Material-Summary and General-Process-Items information. In general, we have been able to derive reliable estimates of Soviet items falling in CEIR Code Categories 02 (Machinery, Excluding Electrical), 03 (Electrical Machinery, Equipment and Supplies), 06 (Fabricated Metal Products), 07 (Chemicals), 08 (Metals, Primary and Secondary), 18 (Metal Ores and Concentrates), 19 (Non-metallic Minerals), as well as materials and labor involved in building construction.

FIGURE VI.1  
ISOPROPYLBENZENE  
FRIEDEL-CRAFTS SYNTHESIS



Flow Rates (lb/hr)								
Material	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Benzene	7,600		23,580		16,465	215	205	16,465
Aluminum Chloride		200						
Polyalkyls			5,165		5,165		5,330	5,165
Catalyst Complex			579		570			570
Ethylene				58.3				
Propylene				3,500				
Butylene				23.3				
Hydrocarbon Gases				5,420	5,420	5,420		
Ethylbenzene					221			221
Isopropylbenzene					10,000			10,000
Butylbenzenes					55.8			55.8

Flow Rates (lb/hr)							
Material	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Benzene	16,670	15,080		690			
Polyalkyls	5,330		5,330				
Catalyst Complex							
Ethylbenzene	221				221		
Isopropylbenzene	10,000					10,000	
Butylbenzenes	55.8						55.8

NOTE: In the small blocks in the diagram above, Roman numerals refer to Operations in TABLE VI.2: Arabic numerals correspond to Process Equipment Items

ISOPROPYLBENZENE  
(FRIEDEL-CRAFTS SYNTHESIS)

TABLE VI.1

## CAPITAL SUMMARY

<u>CEIR Code</u>	<u>CEIR Commodity Group</u>	<u>Quantity</u>	<u>Units</u>
0201	Machine Tools	4.50	MT
0209	Pumps and Compressors	0.240	MT
0217	Refrigeration Equipment	0.375	MT
0222	Industrial Machinery, NEC	162.	MT
0225	Replacement Parts for Other 02 Commodities	2.26	MT
0301	Motors and Generators	0.375	MT
0305	Electrical Measurement and Control Apparatus	0.540	MT
0310	Electrical Machinery and Equipment, NEC	29.5	MT
0406	Trucks	1	U
0407	Passenger Cars	1	U
0501	Mechanical Measuring and Control Instruments	0.533	MT
0603	Heating and Cooking Apparatus (Small Boilers)	0.00135	TMT
0610	Tanks	13.4	MT
0612	Metal Fabrication for Construction	0.376	TMT
0717	Paints, Varnishes	2.50	MT
0805	Ordinary Steel Finished Shapes	0.349	TMT
0806	Quality Steel Finished Shapes	0.00458	TMT
0808	Iron, Steel Forgings	0.0117	TMT
0809	Iron Castings	0.00667	TMT
0811	Primary Copper	3.08	MT
0813	Primary Zinc	1.17	MT
0826	Non-Ferrous Rolling, Drawing	0.250	CM
0827	Non-Ferrous Casting	0.250	CM
1010	Petroleum Coke Residuals, NEC	0.00880	TMT
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TABLE VI.1 (Continued)

CEIR Code	CEIR Commodity Group	Quantity	Units
1401	Round Timber	0.0372	TCM
1402	Saw-Mill Products	0.166	TMT
1403	Wood Products	0.00540	TMT
1404	Furniture	1.90	MT
1601	Refractories	0.00584	TMT
1603	Cement	0.296	TMT
1604	Brick and Hollow Tile	0.548	TMT
1605	Gypsum Products	0.0162	TMT
1606	Lime	0.0344	TMT
1608	Flat Glass	3.00	MT
1609	Non-Metallic Construction Materials, NEC	0.825	TMT
1905	Stone, Sand, and Gravel	3.29	TMT
2300	Services (Incl. Engineering) (US Basis) <sup>(a)</sup>	0.0135	TMY
2400	Labor (USSR Basis) <sup>(a)</sup>	0.0977	TMY

(a) See Table VI.2, Footnote (d).

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ISOPROPYLBENZENE  
(FRIEDEL-CRAFTS SYNTHESIS)

TABLE VI.2

## CAPITAL ITEMS

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
Operation I - Raw Materials Preparation and Handling				
1	Collection Tank, Wet Benzene (5000 gal)	0610	2.5	140
2	Feed Heater (320 sq ft heat-transfer area)	0222	0.64	60
3	Azeotropic Dryer (4.5 ft diam x 26 ft, 14 plates)	0222	14.6	470
4	Reboiler (310 sq ft heat-transfer area)	0222	2.3	58
5	Condenser (345 sq ft heat-transfer area)	0222	0.8	66
6	Separator (200 gal)	0610	0.08	7
7	Heat Exchanger (1400 sq ft heat-transfer area)	0222	1.75	190
8	Collection Tank, Dry Benzene (5000 gal)	0610	2.5	140
9	Pump, Centrifugal (2; ea 55 gpm @ 50 ft head)	0209 0301	0.16) 0.10)	20
10	Dissolving Kettle, Catalyst (500 gal, agitated, steam jacket)	0603	1.8	600
11	Pump, Centrifugal (5 gpm @ 50 ft head)	0209 0301	0.08) 0.05)	10

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TABLE VI. 2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Operation II - Alkylation</u>				
12	Alkylation Column (2; ea 2.5 ft diam x 50 ft, jacketed steel shell with graphite lining)	0222	10.35	480
13	Settling Tank (1500 gal, covered, cone bottom)	0610	0.50	30
14	Condenser (170 sq ft heat-transfer area)	0222	0.44	36
15	Separator (2.5 ft diam x 12 ft)	0222	0.13	4
<u>Operation III - Separation, Absorption and Scrubbing</u>				
16	Depropanizing Column, Alkylate (3 ft diam x 50 ft, 30 plates)	0222	12.19	470
17	Condenser (70 sq ft heat-transfer area)	0222	0.09	14
18	Separator (2 ft diam x 5 ft)	0222	0.08	4
19	Reboiler (70 sq ft heat-transfer area)	0222	0.70	18
20	Cooler, Alkylate (470 sq ft heat-transfer area)	0222	0.82	82
21	Collection Tank, Alkylate (10,000 gal)	0610	2.76	126
22	Absorption Column (1 ft diam x 20 ft, ceramic-ring-packed)	0222 1601	0.91) 0.22)	60
23	Cooler (10 sq ft heat-transfer area)	0222	0.08	4
24	Neutralization Column (1 ft diam x 20 ft, ceramic-ring-packed)	0222 1601 0209	0.91) 0.22) 0.08)	60
25	Pump, Centrifugal (25 gpm @ 100 ft head)	0301	0.05)	10
26	Scrubber (2 ft diam x 20 ft, ceramic-ring-packed)	0222 1601	1.47) 0.86)	120

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TABLE VI. 2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Operation III - Separation, Absorption and Scrubbing (Continued)</u>				
27	Distillation Column (2 ft diam x 50 ft, 30 plates)	0222	8.42	470
28	Condenser (35 sq ft heat-transfer area)	0222	0.56	11
29	Separator (2 ft diam x 5 ft)	0222	0.08	4
30	Depropanizing Column, Polyalkyls (1 ft diam x 20 ft, 15 plates)	0222	2.91	120
31	Condenser (150 sq ft heat-transfer area)	0222	0.40	33
32	Separator (2.5 ft diam x 12 ft)	0222	0.13	4
<u>Operation IV - Catalyst Dissociation</u>				
33	Kettle, Catalyst Dissociation (2000 gal, agitated)	0610	1.32	44
34	Separation Tank (1500 gal)	0610	0.59	32
35	Trap, Baffled Tank, Benzene (1000 gal)	0610	0.44	25
36	Mixing Tank, Caustic (300 gal)	0610	0.48	18
37	Holding Tank, Caustic (3000 gal)	0610	0.97	45
38	Diffusion Mixer (70 gal)	0222	0.23	12
39	Separation Tank (1500 gal)	0610	0.59	32
40	Rinsing Column (4 ft diam x 20 ft, ceramic-ring-packed)	0222 1601	3.35) 3.41)	240
41	Settling Tank (2; ea 4000 gal)	0610	2.4	132
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TABLE VI. 2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Operation V - Rectification</u>				
42	Feed Heater (220 sq ft heat-transfer area)	0222	0.50	45
43	Distillation Column, Benzene (3.5 ft diam x 100 ft, 60 plates)	0222	31.75	750
44	Condenser (600 sq ft heat-transfer area)	0222	1.00	98
45	Separation Tank (800 gal)	0610	0.38	22
46	Reboiler (600 sq ft heat-transfer area)	0222	3.55	98
47	Distillation Column, Technical Isopropylbenzene (4.5 ft diam x 120 ft, 60 plates)	0222	51.92	1,220
48	Condenser (600 sq ft heat-transfer area)	0222	1.00	98
49	Reboiler (400 sq ft heat-transfer area)	0222	2.75	72
50	Distillation Column, Polyalkylbenzenes (1.3 ft diam x 55 ft, ceramic-ring-packed)	0222 1601	2.16 1.13	180
51	Condenser (30 sq ft heat-transfer area)	0222	0.14	10
52	Reboiler (20 sq ft heat-transfer area)	0222	0.38	7
53	Distillation Column, Ethylbenzene (2.5 ft diam x 80 ft, 60 plates)	0222	17.95	470
54	Condenser (200 sq ft heat-transfer area)	0222	0.48	42
55	Reboiler (140 sq ft heat-transfer area)	0222	1.10	32
56	Rectification Column, Isopropylbenzene (3 ft diam x 130 ft, 60 plates)	0222	22.39	470
57	Condenser (800 sq ft heat-transfer area)	0222	1.20	120
58	Reboiler (240 sq ft heat-transfer area)	0222	2.00	48
59	Cooler (170 sq ft heat-transfer area)	0222	0.43	36

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TABLE VI. 2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Operation VI - Storage</u>				
60	Storage Tank, Isopropylbenzene (2; ea 150,000 gal)	0612 0805	(37.0) 37.0	1,840
61	Storage Tank, Butylbenzene (2000 gal)	0610	0.60	40
62	Storage Tank, Ethylbenzene (7500 gal)	0610	1.75	103
Total Weight of Process Equipment (exclusive of CEIR Code 0612)			231.43MT	
Total Labor for Installation of Process Equipment				10,302
<u>Auxiliary Items</u>				
63	Improved Land			5,140
64	Ventilation:			
	Stack (60 ft)	0222	1.2	50
	Ducts (36 in. sq x 300 ft)	0612	(2.8)	
		0805	2.8	675
	Fans and Blowers (3; ea 15,000 scfm @ 3 in. H <sub>2</sub> O head)	0222 0301	8.1 0.3	357
65	Refrigeration System (1.5 ton)	0217	0.5	300
66	Pipe, Valves and Fittings:			
	Metal Fabrication for Construction	0612	(110. )	
	Ordinary Steel Finished Shapes	0805	73.9	
	Quality Steel Finished Shapes	0806	6.11	
	Iron, Steel Forgings	0808	15.6	
	Iron Castings	0809	8.89	
	Primary Copper	0811	4.11	
	Primary Zinc	0813	1.56	
	Non-Ferrous Rolling, Drawing	0826	(0.333)(CM)	
	Non-Ferrous Casting	0827	(0.333)(CM)	
	Non-Metallic Construction Material, NEC	1609	1.00	15,400

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TABLE VI.2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Auxiliary Items (Continued)</u>				
67	Foundations for Equipment:			
	Reinforcing Rod	0612	(26.5)	
		0805	26.5)	
	Cement	1603	64.0)	
	Sand, Stone, and Gravel	1905	550. )	1,800
68	Paint	0717	2.50	2,310
69	Insulation for Equipment and Piping	1609	5.79	2,570
70	Structural Steel for Equipment	0612	(255. )	
		0805	255. )	1,390
71	Electricals (Motors less than 5 hp and miscellaneous electrical supplies)	0310	39.3	6,570
72	Instruments	0305	0.72)	
		0501	0.71)	1,030
73	Maintenance:			
	Machine Tools	0201	6.00	1,500
	Replacement Parts for Other 02 Commodities	0225	3.01	
74	Buildings (20,000 sq ft floor area) <sup>(c)</sup>			
	Ordinary Steel Finished Shapes	0612	(52.4)	
		0805	52.4)	
	Petroleum Coke Residuals, NEC	1010	8.80)	
	Round Timber	1401	37.2) (CM)	
	Saw Mill Products	1402	166. )	
	Wood Products	1403	5.40)	
	Cement	1603	232. )	
	Brick, Hollow Tile	1604	548. )	
	Gypsum Products	1605	16.2 )	
	Lime	1606	34.3 )	
	Flat Glass	1608	3.00)	
	Non-Metallic Construction Material, NEC	1609	818. )	
	Sand, Stone, and Gravel	1905	2,740. )	
	Office Furniture	1404	1.90)	98,600

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TABLE VI.2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Auxiliary Items (Continued)</u>				
75	Plant Transportation:			
	Fork-lift Truck	0222	1.0	
	Truck	0406	1 (U)	
	Passenger Car	0407	1 (U)	
76	Services (Includes Engineering)	2300		32,500
<u>Installation Labor Summary<sup>(d)</sup></u>				
	USSR Basis	2400		98,600
	US Basis	2400		(49,394)
	US Normalized to USSR Basis	2400		135,800
	Total Installation Labor USSR Basis	2400		234,400

(a) Material of construction is mild steel unless otherwise specified. All equipment-weight and labor-of-installation data are US basis unless otherwise specified. A factor of 0.75 is used to convert the weight of metallic items in this table to the USSR basis presented in the Capital Summary table(9).

(b) Metric tons (MT) unless otherwise noted.

(c) Data are USSR basis except for the estimated floor area.

(d) Installation labor on Buildings is based on USSR practice; all other installation labor is based on US practice. The installation labor reported for CEIR Code 2400 in the Capital Summary table is on a USSR basis, US labor being converted to USSR labor by applying a normalizing factor of 2.75(9). Labor under CEIR Code 2300 is on a US basis in all tables.

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**ISOPROPYLBENZENE**  
(FRIEDEL-CRAFTS SYNTHESIS)

TABLE VI. 3

## MATERIAL SUMMARY

Material Input				
Material	Input/30 Days(a)	CEIR	Specification	
	Quantity	Units		
Benzene	2480	MT	1007	Thiophene-free, 0.07% water
Olefins	2940	MT	0714	40.0% propylene, 58.8% hydrocarbons, 1.0% ethylene, 0.2% butylene (refinery gas)
Aluminum chloride	0.0652	TMT	0711	Granular, 97.5%
Caustic	0.122	TMT	0711	50% caustic soda
Maintenance Mat'ls	1.481	MT	0225	Replacement parts

Material Output				
Material	Output/30 Days(a)	CEIR	Specification	
	Quantity	Units		
Isopropylbenzene	3265	MT	0714	100% basis
Ethylbenzene	73.6	MT	0714	98% product
Butylbenzenes	18.21	MT	0714	
Hydrocarbon	1770	MT	0714	Hydrocarbon gas returned to refinery
Benzene	225			(100% basis) contaminated benzene

(a) Operating days.

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**ISOPROPYLBENZENE**  
(FRIEDEL-CRAFTS SYNTHESIS)

TABLE VI. 4

## GENERAL PROCESS ITEMS

Rated Annual Capacity 97.5% Isopropylbenzene	39,000	MT <sup>(a)</sup>
Percent of rated annual capacity realizable:		
1st year	75	%
2nd year	85	%
3rd year	95	%
4th year	98	%
Maximum Realizable Short-Term Capacity	103	%
Labor Input to Process <sup>(b)</sup>		
US Basis	315,000	Man-Hr/Yr (9)
USSR Basis	945,000	Man-Hr/Yr (9)
Labor Scale Factor	0.7 <sup>(c)</sup>	
Range of applicability of scale factor:		
Lower limit	0.2 <sup>(d)</sup>	
Upper limit	2.0 <sup>(d)</sup>	
Electrical Input per Year	1,960,000	KWH (7)
Water Input per Year	1,230,000	MT (7)
Net Fuel Input per Year	200,000	MM BTU (7)
Process Heat Other Than Steam	-	MM BTU
Time Required to Build New Plant	11	Months

(a) Based on 350 days per year operation at 100% mechanical efficiency.

(b) For a partially-automated plant.

(c) Exponential factor for rated annual plant capacity.

(d) Multiplicative factor for rated annual plant capacity. STAT

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SECTION VIIPHENOL AND ACETONE

STAT

### INTRODUCTION

Since our study is concerned only with the Soviet chemical industry, this report considers only synthetic phenol and not the coke-oven product of the steel industry, which contributes importantly to total USSR production.

The following processes are used in the USSR for the synthesis of phenol:

1. Sulfonation of benzene and fusion of the sulfonate with alkali (1, 2, 3).
2. Hydrolysis of chlorobenzene (4, 1, 2)
3. Oxidation of isopropylbenzene (cumene) and hydrolysis of the oxidized product (5).

Kruzhlov and Sergeev, who pioneered the establishment of a Soviet plant using the last method, included a brief economic analysis of all three processes in an article devoted primarily to a discussion of the cumene route (6). Bibishev also touched upon the matter (7). The cumene process was considered superior to the other two, particularly, because it does not require large amounts of auxiliary chemicals such as chlorine, caustic, or sulfuric acid. A second advantage was the concurrent production of acetone. The chlorobenzene process was considered economical only when substantial amounts of cheap chlorine were available.

The cumene process became operative in the USSR in 1949 (6, 5). Before that time, both of the other processes appear to have been used (1, 2). In view of a probably heavy demand for chlorobenzene for DDT and other applications, we would guess that the Soviets now favor the sulfonation route over the chlorobenzene method.

This report at present describes only a plant for manufacture of phenol from isopropylbenzene. Plant size (20,000 metric tons of phenol and 12,400 metric tons of acetone per year) and some information concerning equipment were obtained from the report of the visit of the US Plastics Industry exchange delegation to the USSR in 1958 (8). That section of the Grozny petroleum complex which was observed by the delegation is therefore detailed in this report and in our report on isopropylbenzene.

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In future work, it may be desirable to delineate more comprehensively the Soviet capability for synthesizing phenol by designing a plant which uses the sulfonation technique. Nekrasov (9) gave an arbitrary output of phenol (20,000 metric tons per year) by this method without reference to production facilities and some process information is available (1, 2, 10).

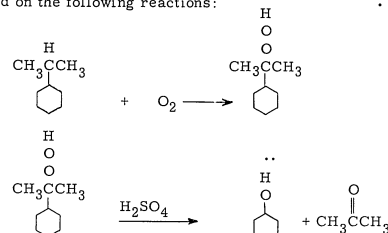
Significant quantities of at least one important by-product are obtained from the Grozny plant (8). About 300 metric tons of  $\alpha$ -methylstyrene are recovered each year. However, until recently, the acetophenone produced was discharged in the waste liquor. In the summer of 1958, there were plans in existence for its recovery. The potential Soviet output of these materials may be estimated from figures for the Hercules Powder Co.'s phenol plant at Gibbstown, N. J., which employs manufacturing techniques similar to those used at Grozny (11). The annual output of phenol at Gibbstown is only 13,000 short tons. Ratioing from the US figures, one would be led to expect the Grozny operation to obtain the following: 13,200 metric tons of acetone, 2,200 metric tons of  $\alpha$ -methylstyrene and 1,320 metric tons of acetophenone. From the apparent low output of  $\alpha$ -methylstyrene at Grozny, one would not expect a high recovery of acetophenone. The large difference in by-product recovery between US and Soviet practice is felt to stem from the desire in the USSR to maximize the conversion of cumene to phenol. In the US, there is a sufficient demand for  $\alpha$ -methylstyrene to warrant the operation of the versatile cumene process in a manner to favor a substantial conversion to this material.

While the equipment of a synthetic phenol plant could probably be adapted to the production of other phenolic compounds, such as cresol (from toluene), and betanaphthol (from naphthalene) or to the production of polyalkyl compounds, such as diisopropylbenzene, the strategic nature of phenol itself would argue against the feasibility of setting up a significant substitution potential, save for  $\alpha$ -methylstyrene, as already indicated.

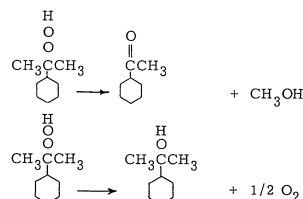
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# PROCESS DESCRIPTION

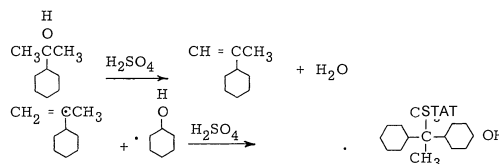
The production of phenol and acetone from cumene (isopropylbenzene) is based on the following reactions:



The first reaction, oxidation of cumene to cumene hydroperoxide, is accompanied by the following side reactions which produce some acetophenone, methanol and dimethylphenylcarbinol:



The second reaction, dissociation of cumene hydroperoxide to phenol and acetone, is quantitative. However, the following secondary reactions accompany it to produce some  $\alpha$ -methylstyrene,  $\alpha$ - $\alpha$ -dimethylbenzylphenol and mesityl oxide:



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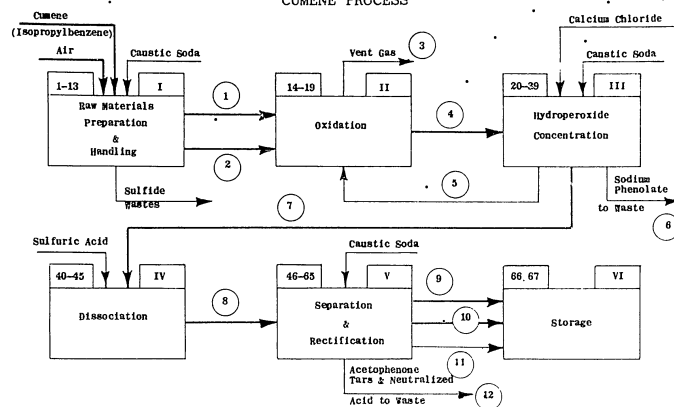
The raw materials for the production of phenol and acetone are cumene, air and sulfuric acid. The sulfuric acid catalyzes the dissociation of cumene hydroperoxide to phenol and acetone; however, it is not recovered in the process and a continual input is required.

Cumene is pumped from storage to a feed tank, which also acts as a receiver for recycle cumene. From the feed tank, the cumene is passed through a product-to-feed heat exchanger and a preheater to five oxidation columns, where compressed air is introduced for oxidation of the cumene to cumene hydroperoxide. The raw air is initially scrubbed with caustic solution to remove sulfur compounds and dried before introduction into the oxidation columns. The oxidation is carried out at 230°F and a pressure of 3 atmospheres, which results in about 25% conversion of the cumene to cumene hydroperoxide. The reaction is exothermic and the excess heat is removed through water cooling coils on the plates of the columns. The gases leaving the oxidation columns are passed through a condenser to a separator, where spent air is vented to the atmosphere. From here the liquefied cumene is sent to a recycle-collection tank.

The liquid reaction products from the oxidation columns are passed through the product-to-feed heat exchanger into two receiving tanks. From the receiving tanks, the reaction products are preheated and sent through two vacuum distillation columns in series. The overhead product from the vacuum distillation is cumene which is condensed and sent to the recycle-collection tank. The cumene is washed with 5% caustic solution in the collection tank and separated from the aqueous layer in a separating column. It is dried by passing it through a calcium chloride packed column then through a sodium hydroxide packed column. After drying, it is recycled to the cumene feed tank for further oxidation. The bottoms from the vacuum distillation, containing concentrated cumene hydroperoxide and small amounts of acetophenone and dimethylphenylcarbinol, are sent to the dissociation column, which is filled with a mixture of phenol and acetone containing 1% sulfuric acid. The cumene hydroperoxide dissociates quantitatively in their medium to phenol and acetone. The reaction is exothermic and is carried out under reflux conditions. The products of dissociation pass from the column through a large cooler. A portion of the cooled reaction mixture is recycled to the column to maintain the reaction temperature between 104 and 140°F. The remainder is neutralized by an aqueous caustic solution and is sent to a five-column aggregate for rectification.

Crude acetone is removed overhead from the first distillation column, condensed and sent to the second distillation column, where commercial acetone is taken off overhead, condensed and sent to storage.

FIGURE VII A 1  
PHENOL AND ACETONE  
CUMENE PROCESS



Flow Rates (lb/hr)												
Material	1	2	3	4	5	6	7	8	9	10	11	12
Cumene		8,400		10,500	10,500							
Air	12,700											
Vent Gases			10,467									
Cumene Hydroperoxide				9,900		9,900						
Phenol				190		190 <sup>(*)</sup>		6,110		6,110		
Acetone				107		107		3,790	3,790			
α Methyl Styrene				91			91	91			91	
Acetophenone, Resins and Tars				345			345	345	STAT			345

NOTE: In the small blocks in the diagram above, Roman numerals refer to operations in TABLE VII A 2. Arabic numerals correspond to Process Equipment Items.

(\*) Discharged as sodium phenolate.

The bottoms from the first distillation column are sent to the third distillation column where phenol,  $\alpha$ -methylstyrene and water are distilled off. Further purification is carried out in the fourth and fifth columns where phenol is separated from water and  $\alpha$ -methylstyrene. Acetophenone and resins are withdrawn as vat residue from the third column and discarded. The purified phenol removed overhead in the fifth column is condensed and sent to storage.  $\alpha$ -methylstyrene is recovered from the vat residue and sent to storage.

The controlling factors in the process are the temperature and pressure during oxidation and the temperature and acid concentration during the dissociation of the hydroperoxide. It is important that the air used for oxidation be free of sulfur compounds and that all phenol is removed from the recycled cumene, since these compounds inhibit the oxidation step.

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PROCESS DATA

Standardized tables containing the results of our study of the Soviet process for the production of phenol and acetone by the cumene process are presented in this section. Tables VII. 1-VII. 4, which follow, tabulate the process data in terms of input-output quantities.

While the technical details of the process have been drawn from Soviet practice (1-10), the equipment information has been derived primarily from US sources (12). Wherever possible, auxiliary-item inputs, such as piping, electricals, maintenance, etc., have been estimated from overall factors derived from US experience, with appropriate adjustment for Soviet practice. Detailed descriptions of methods of sizing equipment and computing the corresponding values of weights and labor of installation are presented in our Chemical-Process Calculation Manual (12). Where it has been necessary to approximate the input quantities for a special item of equipment, such as a furnace, or to estimate certain over-all factors from US practice, this is indicated by an asterisk(\*) following the item number in the Capital-Items table. In general, calculations of this nature will only be shown in our basic process engineering work sheets.

Process information actually derived from Soviet sources is indicated by reference. We have provided for the estimation of major differences between US and Soviet practice by means of average labor- and weight-conversion factors. Thus, while the majority of the Capital-Items information is expressed on the US basis, the Capital-Summary figures are, for the most part, estimates of actual Soviet practice. The last is also true of the Material-Summary and General-Process-Items information. In general, we have been able to derive reliable estimates of Soviet items falling in CEIR Code Categories 02 (Machinery, excluding Electrical), 03 (Electrical Machinery, Equipment and Supplies), 06 (Fabricated Metal Products), 07 (Chemicals), 08 (Metals, Primary and Secondary), 18 (Metal Ores and Concentrates), 19 (Non-Metallic Minerals), as well as materials and labor involved in building construction.

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PHENOL AND ACETONECUMENE PROCESSTABLE VII. 1CAPITAL SUMMARY

<u>CEIR Code</u>	<u>CEIR Commodity Group</u>	<u>Quantity</u>	<u>Units</u>
0201	Machine Tools	4.50	MT
0209	Pumps and Compressors	37.0	MT
0222	Industrial Machinery, NEC	193.	MT
0225	Replacement Parts for Other 02 Commodities	4.10	MT
0301	Motors and Generators	6.03	MT
0305	Electrical Measurement and Control Apparatus	1.96	MT
0310	Electrical Machinery and Equipment, NEC	53.6	MT
0404	Freight Cars	4	U
0406	Trucks	2	U
0407	Passenger Cars	1	U
0501	Mechanical Measuring and Control Instruments	2.61	MT
0610	Tanks	76.9	MT
0612	Metal Fabrication for Construction	0.314	TMT
0706	Caustic Soda	1.73	MT
0711	Inorganic, NEC	0.00171	TMT
0717	Paints, Varnishes	4.54	MT
0805	Ordinary Steel Finished Shapes	0.264	TMT
0806	Quality Steel Finished Shapes	0.00833	TMT
0808	Iron, Steel Forgings	0.0212	TMT
0809	Iron Castings	0.0122	TMT
0811	Primary Copper	5.61	MT
0813	Primary Zinc	2.12	MT
0826	Non-Ferrous Rolling, Drawing	0.455	CM
0827	Non-Ferrous Casting	0.455	CM

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TABLE VII.1 (Continued)

CEIR Code	CEIR Commodity Group	Quantity	Units
1010	Petroleum Coke Residuals, NEC	0.0132	TMT
1401	Round Timber	0.0558	TCM
1402	Saw-Mill Products	0.249	TMT
1403	Wood Products	0.00810	TMT
1404	Furniture	2.86	MT
1601	Refractories	0.00750	TMT
1603	Cement	0.463	TMT
1604	Brick and Hollow Tile	0.822	TMT
1605	Gypsum Products	0.0243	TMT
1606	Lime	0.0516	TMT
1608	Flat Glass	4.50	MT
1609	Non-Metallic Construction Materials, NEC	1.24	TMT
1905	Stone, Sand, and Gravel	5.00	TMT
2300	Services (Incl. Engineering) (US Basis)(a)	0.0213	TMY
2400	Labor (USSR Basis)(a)	0.1679	TMY

(a) See Table VII.A.2, Footnote (d).

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## PHENOL AND ACETONE

## CUMENE PROCESS

TABLE VII.2

## CAPITAL ITEMS

Item No.	Process Equipment(a)	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
Operation I - Raw Materials Preparation and Handling				
1	Air Filter, Impingement Type (2; ea 2100 SCFM)	0222	1.34	20
2	Make-up Tank, Caustic (1000 gal, agitated)	0610	0.89	28
3	Pump, Centrifugal (75 gpm @ 100 ft head)	0209 0301	0.08) 0.05)	10
4	Scrubbing Tower (5 ft diam x 35 ft; 25 ft of 2-in. ceramic Raschig ring packing)	0222 1601	4.09) 7.50)	470
5	Entrainment Separator (2100 SCFM)	0222	0.67	10
6 *	Compressor, 2-Stage (3; ea 2500 SCFM @ 100 psig)	0209 0301	24.63) 6.36)	5,220
7	De-mister (2; ea 500 SCFM, 100 psig working pressure)	0222	0.55	10
8 *	Absorption Column (4; ea 2.5 ft diam x 12 ft, packed with 6-mesh silica gel, 100 psig working pressure)	0222	10.20	520
9	Pump, Centrifugal (2; ea 500 gpm @ 50 ft head)	0209 0301	0.26) STAT	44

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TABLE VII. 2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Operation I - Raw Materials Preparation and Handling (Cont'd)</u>				
10	Storage Tank, Cumene (2; ea 40,000 gal)	0612 0805	(16.40) 16.40	880
11	Pump, Centrifugal (2, ea 200 gpm @ 50 ft head)	0209 0301	0.35 0.19	30
12	Feed and Recycle Receiver Tank (10,000 gal)	0610	2.76	126
13	Pump, Centrifugal (100 gpm @ 100 ft head)	0209 0301	0.18 0.10	15
<u>Operation II - Oxidation</u>				
14	Heat Exchanger (90 sq ft heat-transfer area, chrome-nickel-steel)	0222	0.11	22
15	Preheater, Cumene (700 sq ft heat-transfer area)	0222	1.10	110
16	Oxidation Column (5; ea 4 ft diam x 50 ft, 8 trays, chrome-nickel-steel, 45 psig working pressure)	0222	45.5	2,350
17	Condenser (520 sq ft heat-transfer area)	0222	0.90	87
18	Gas Separator (700 gal)	0610	0.43	23
19	Receiving Tank (2; ea 5000 gal, chrome-nickel-steel)	0610	2.83	156

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TABLE VII. 2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Operation III - Hydroperoxide Concentration</u>				
20	Pump, Centrifugal (75 gpm @ 100' ft head)	0209 0301	0.08 0.05	10
21	Feed Preheater (210 sq ft heat-transfer area)	0222	0.21	47
22	Vacuum Distillation Column, Primary (8 ft diam x 50 ft, 15 plates)	0222	68.83	1,500
23	Reboiler (480 sq ft heat-transfer area)	0222	3.05	82
24	Condenser (500 sq ft heat-transfer area)	0222	0.46	85
25	Ejector (1.5 in. Hg working pressure)	0209	0.26	10
26	Receiving and Scrubbing Tank, Cumene (2; ea 20,000 gal, agitated)	0610	10.40	540
27	Pump, Centrifugal (75 gpm @ 50 ft head)	0209 0301	0.08 0.05	10
28	Storage Tank, Bottoms (2, ea 20,000 gal)	0610	9.96	415
29	Vacuum Distillation Column, Secondary (5 ft diam x 40 ft, 12 plates)	0222	16.22	470
30	Reboiler (260 sq ft heat-transfer area)	0222	2.13	51
31	Condenser (325 sq ft heat-transfer area)	0222	0.30	61
32	Ejector (0.28 in. Hg working pressure)	0209	0.26	10
33	Pump, Centrifugal (75 gpm @ 50 ft head)	0209 0301	0.08 STAT	10

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TABLE VII. 2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Operation III - Hydroperoxide Concentration (Cont'd)</u>				
34	Storage Tank, Cumene Hydroperoxide (4; ea 5000 gal)	0610	5.81	312
35	Make-up Tank, Caustic (5000 gal, agitated)	0610	2.05	90
36	Pump, Centrifugal (1; 200 gpm @ 50 ft head - 1, 50 gpm, 150 ft head)	0209 0301	0.21) 0.23)	32
37	Decanter (2; ea 2000 gal)	0610	1.44	80
38	Drying Column (4 ft diam x 10 ft, packed with calcium chloride)	0222 0711	1.03) 1.71)	230
39	Drying Column (4 ft diam x 10 ft, packed with sodium hydroxide)	0222 0706	1.03) 1.73)	230
<u>Operation IV - Dissociation</u>				
40	Holding Tank, Sulfuric Acid (2, ea 2000 gal, rubber-lined)	0610	2.28	120
41	Pump, Centrifugal (100 gpm @ 50 ft head)	0209 0301	0.08) 0.05)	10
42	Dissociation Column (3; ea 3.5 ft diam x 8 ft, chrome-nickel-steel)	0222	1.08	57
43	Cooler (3, ea 440 sq ft, heat-transfer area, stainless-steel)	0222	1.11	231
44	Condenser (3; ea 100 sq ft heat-transfer area, chrome-nickel-steel)	0222	0.36	72
45	Receiving Tank (2; ea 20,000 gal)	0610	9.96	415

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TABLE VII. 2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Operation V - Separation and Rectification</u>				
46	Pump, Centrifugal (100 gpm @ 50 ft head)	0209 0301	0.08) 0.05)	10
47	Distillation Column, Primary (6 ft diam x 80 ft, 25 plates)	0222	41.43	750
48	Reboiler (260 sq ft heat-transfer area)	0222	2.13	51
49	Condenser (350 sq ft heat-transfer area)	0222	0.31	85
50	Receiving Tank, Crude Acetone (8000 gal)	0610	2.22	109
51	Pump, Centrifugal (50 gpm @ 50 ft)	0209 0301	0.08) 0.05)	10
52	Receiving Tank, Crude Phenol (15,000 gal)	0610	7.30	385
53	Pump, Centrifugal (50 gpm @ 100 ft head)	0209 0301	0.08) 0.05)	10
54	Distillation Column, Acetone (3 ft diam x 40 ft, 15 plates)	0222	9.04	470
55	Reboiler (190 sq ft heat-transfer area)	0222	1.50	40
56	Condenser (300 sq ft heat-transfer area)	0222	0.28	57
57	Pump, Centrifugal (50 gpm @ 50 ft head)	0209 0301	0.08) 0.05)	10
58	Distillation Column; Phenol (3; ea 3 ft diam x 40 ft, 15 plates)	0222	27.12	1,410
59	Reboiler (3; ea 500 sq ft heat-transfer area)	0222	9.45	255
60	Condenser (3; ea 740 sq ft heat-transfer area)	0222	3.45	345

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TABLE VII. 2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Operation V - Separation and Rectification (Cont'd)</u>				
61	Ejector (1; 3 in. Hg, 1-stage - 1; 2 in. Hg, 2-stage - 1; 1 in. Hg, 2-stage)	0209	0.57	30
62	Pump, Centrifugal (2; ea 50 gpm @ 100 ft head - 1; 50 gpm @ 50 ft head - 1; 25 gpm @ 50 ft head)	0209 0301	0.24 0.20	40
63	Receiving Tank, Distillate (2; ea 8000 gal, glass-lined-steel)	0610	8.30	430
64	Receiving Tank, Phenol (8000 gal, stainless-steel)	0610	4.44	218
65	Receiving Tank, Alpha-Methylstyrene (500 gal)	0610	0.28	15
<u>Operation VI - Storage</u>				
66	Pump, Centrifugal (2; ea 50 gpm @ 50 ft head - 1; 25 gpm @ 50 ft head)	0209 0301	0.24 0.15	30
67	Storage Tank (3, ea 25,000 gal, stainless-steel - 2; ea 25,000 gal, steel - 1; 4000 gal, steel)	0610	31.20	1,266
Total Weight of Process Equipment (exclusive of CEIR Code 0612)			420.83 MT	
Total Labor for Installation of Process Equipment				21,337

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TABLE VII. 2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Auxiliary Items</u>				
68	Improved Land			9,350
69	Pipe, Valves and Fittings: Metal Fabrication for Construction Ordinary Steel Finished Shapes Quality Steel Finished Shapes Iron, Steel Forgings Iron Castings Primary Copper Primary Zinc Non-Ferrous Rolling, Drawing Non-Ferrous Casting Non-Metallic Construction Material, NEC	0612 0805 0806 0808 0809 0811 0813 0826 0827 1609	(200. ) 134. ) 11.1 ) 28.3 ) 16.2 ) 7.48 ) 2.83 ) ( 0.606)(CM) ( 0.606)(CM) 1.82 )	28,100
70	Foundations for Equipment: Reinforcing Rod  Cement Sand, Stone, and Gravel	0612 0805 1603 1905	( 44.0 ) 44.0 ) 115. ) 890. )	5,100
71	Paint	0717	4.54	4,210
72	Insulation for Equipment and Piping	1609	10.5	4,670
73	Structural Steel for Equipment	0612 0805	( 52.9 ) 52.9 )	2,880
74	Electricals (Motors less than 5 hp and miscellaneous electrical supplies)	0310	71.5	12,000
75	Instruments	0305 0501	2.61 ) 2.61 )	3,740
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TABLE VII.2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Auxiliary Items (Cont'd)</u>				
76	Maintenance:			
	Machine Tools	0201	6.0	1,500
	Replacement Parts for Other 02 Commodities	0225	5.47	
77	Buildings (30,000 sq ft floor area) <sup>(c)</sup>			
	Ordinary Steel Finished Shapes	0612	(78.6 )	
		0805	78.6 )	
	Petroleum Coke Residuals, NEC	1010	13.2 )	
	Round Timber	1401	55.8 ) (CM)	
	Saw-Mill Products	1402	249. )	
	Wood Products	1403	8.10 )	
	Cement	1603	348. )	
	Brick, Hollow Tile	1604	822. )	
	Gypsum Products	1605	24.3 )	
	Lime	1606	51.6 )	
	Flat Glass	1608	4.50 )	
	Non-Metallic Construction Material, NEC	1609	1,230. )	
	Sand, Stone, and Gravel	1905	4,110. )	
	Office Furniture	1404	2.86 )	148,000
78	Plant Transportation:			
	Fork Lift (2)	0222	2.0 (U)	
	Tank Car	0404	4 (U)	
	Truck	0406	2 (U)	
	Passenger Car	0407	1 (U)	
79	Services (Includes Engineering)	2300		51,000

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TABLE VII.2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Installation Labor Summary<sup>(d)</sup></u>				
	USSR Basis	2400		148,000
	US Basis	2400		( 92,900)
	US Normalized to USSR Basis	2400		255,000
	Total Installation Labor USSR Basis	2400		403,000

(a) Material of construction is mild steel unless otherwise specified. All equipment-weight and labor-of-installation data are US basis unless otherwise specified. With the exception of Item 6, a factor of 0.75 is used to convert the weight of metallic items in this table to the USSR basis presented in the Capital-Summary table (12). A factor of 1.4 is used to convert the weight of item 6 to a USSR Basis (12).

(b) Metric tons (MT) unless otherwise noted.

(c) Data are USSR basis except for the estimated floor area.

(d) Installation labor under Buildings is based on USSR practice; all other installation labor is based on US practice. The installation labor reported for CEIR Code 2400 in the Capital Summary table is on a USSR basis, US labor being converted to USSR labor by applying a normalizing factor of 2.75 (12). Labor under CEIR Code 2300 is on a US basis in all tables.

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PHENOL AND ACETONECUMENE PROCESSTABLE VII.3MATERIAL SUMMARYMaterial Input

<u>Material</u>	<u>Input/30 Days<sup>(a)</sup></u>		<u>CEIR</u>	<u>Specification</u>
	<u>Quantity</u>	<u>Units</u>		
Cumene	2760	MT	0714	Commercial (b.p. 152-153°F)
Sulfuric Acid	0.0015	TMT	0703	Commercial Oil of Vitriol (93-98%)
Caustic Soda	27.4	MT	0706	Technical (92% NaOH)
Calcium Chloride	0.0016	TMT	0711	Technical (anhydrous)
Maintenance	2.69	MT	0255	Replacement parts

Material Output

<u>Material</u>	<u>Output/30 Days<sup>(a)</sup></u>		<u>CEIR</u>	<u>Specification</u>
	<u>Quantity</u>	<u>Units</u>		
Phenol	2000	MT	0714	Technical (>98%)
Acetone	1240	MT	0714	Technical (99.5%)
α-Methyl Styrene	29.7	MT	0714	Technical

(a) Operating days.

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PHENOL AND ACETONECUMENE PROCESSTABLE III.4GENERAL PROCESS ITEMS

Rated Annual Capacity	phenol 20,000 MT <sup>(a)</sup> acetone 12,400 MT <sup>(a)</sup>
Percent of rated annual capacity realizable:	
1st year	75 %
2nd year	85 %
3rd year	95 %
4th year	98 %
Maximum Realizable Short Term Capacity	103 %
Labor Input to Process <sup>(b)</sup>	
US Basis	112,000 Man-Hr/Yr
USSR Basis	336,000 Man-Hr/Yr (12)
Labor Scale Factor	0.7 <sup>(c)</sup>
Range of applicability of scale factor:	
Lower limit	0.2 <sup>(d)</sup>
Upper limit	2.0 <sup>(d)</sup>
Electrical Input Per Year	3,670,000 KWH
Water Input Per Year	833,000 MT
Net Fuel Input Per Year	73,300 MM BTU
Process Heat Other Than Steam	- MM BTU
Time Required to Build New Plant	12 Months

(a) Based on 300 days per year operation at 100% mechanical efficiency.

(b) Assumes a partially-automated plant.

(c) Exponential factor for rated annual plant capacity.

(d) Multiplicative factor for rated annual plant capacity. .STAT

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SECTION VIIIMONONITROTOLUENES

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#### INTRODUCTION

Although the nitration of aromatic hydrocarbons has been treated in a general way in the Soviet literature (1), we found no specific information on the production of the mononitrotoluenes. Undoubtedly, these chemicals are produced in the USSR. Shereshevskii (2) gave USSR specifications for ortho-nitrotoluene and stated that the material was used in the dye and munitions industries.

The processes for the manufacture of the mononitrotoluenes are very similar to those used for mononitrobenzene. There is, however, an important point of difference. While mononitrobenzene exists in a single form, three isomers of mononitrotoluene are known. Separation of the individual mononitrotoluene compounds thus requires a few unit operations not necessary in the production of mononitrobenzene.

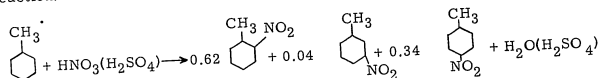
In the present report, the two plants that were designed for nitrobenzene (see our report on that substance) have been adapted for production of nitrotoluene; equipment for the separation of the isomers has been added. Capacity of the plants for production of mononitrotoluene was computed from the equipment sized for nitrobenzene manufacture.

This report emphasizes the versatility and substitution potential of the nitration apparatus. Other chemicals, such as the nitronaphthalenes, could no doubt be conveniently produced in the plant described in this report.

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## PROCESS DESCRIPTION

The production of mononitrotoluenes is based on the following reaction:



The ortho-, meta- and para-isomers are produced in approximately the percentages indicated, the relative yields being influenced only slightly by the conditions employed during nitration. The raw materials required for the production of nitrotoluenes are toluene, nitric acid and sulfuric acid. Nitration can be accomplished with nitric acid alone; however, common industrial practice employs a mixed acid as indicated above. The sulfuric acid promotes the reaction by removing the water formed during nitration. The sulfuric acid is recovered, concentrated and recycled to the process.

Two plants are described in this report: one employing a batch operation throughout the process, the other employing a continuous operation for the nitration, separation, washing and neutralization steps, with the remainder of the process batch operated. Each plant has the same annual output capacity and carries out essentially identical operations. The major differences lie in the type, weight and number of pieces of process equipment items required in the steps that are operated on a batch or continuous basis. The batch-operated plant requires larger-capacity equipment than one employing continuous operation. Consequently, the former has a greater total weight of process equipment.

In the processes, concentrated nitric and sulfuric acid are pumped from storage to a mixing tank to provide the mixed acid for nitration. This mixed acid contains approximately 36% by weight of nitric acid and 64% by weight of sulfuric acid. Mixed acid and toluene are introduced into the nitration tanks to provide essentially the stoichiometric amounts of nitric acid and toluene required for the reaction. The reaction is exothermic, the heat of reaction being removed by cooling water circulated through jackets on the batch nitration tanks and through cooling coils in the continuous nitration tanks. The products of the nitration step are sent to separators where the spent acid is removed in the bottom layer. The spent acid is sent to a retort where it is directly contacted with hot gases which flow counter-current to the acid. The hot gases, produced by burning liquid fuel, drive off any small amount of nitric acid remaining and remove water from the sulfuric acid. The output of the retort, consisting of 93% sulfuric acid, is cooled and pumped to storage for reuse in the production of mixed acid for nitration.

The nitrotoluenes are sent to washers after separation where they are contacted with caustic soda and water to neutralize their acid content. In the batch process, the washers are equipped for steam distillation, the operation which follows washing. In the continuous process, the nitrotoluenes move from the washers to separators where water is removed. The washed product is then pumped to assembly tanks, equipped for steam distillation. The steam distillation strips out low-boiling components, which are sent to waste. The nitrotoluenes are sent to vacuum dryers following steam distillation. The dried product is sent to the batch distillation and crystallization operations for isomer separation and purification.

In the primary distillation column, the overhead product is removed and discarded until the crystallization point of the still liquor reaches 14° F; then ortho-nitrotoluene, contaminated with small amounts of the meta- and para-isomer, is removed overhead, condensed and sent to storage. When the crystallization point of the still liquor reaches 104° F, distillation is continued without a column; the distillate is cooled and sent to crude para-nitrotoluene storage.

Crude para-nitrotoluene is sent to crystallizers, where it is cooled to 102-104° F and held at that temperature for 24 hours. It is then cooled to 64-65° F and held at that temperature for 24 hours. The crystallizers are then opened and the mother liquor collected and stored. The crystals are heated slowly over a period of 16 hours to 122° F. When the crystallization point of the liquids coming off reaches 120.2° F, pure para-nitrotoluene (crystallization point 123.8° F) is melted out, re-crystallized, centrifuged and sent to storage. The liquid removed during the heating period is recycled to the next batch of crude going to the crystallizer.

The mother liquors from the para-nitrotoluene crystallization are sent to the secondary distillation column. The first overhead fraction, containing mainly ortho-isomer, and the subsequent fraction, containing 50% meta- and the rest largely ortho-isomer, are collected. When the crystallization point of the still liquor reaches 104° F, distillation is continued without a column, the distillate being sent to crude para-nitrotoluene storage for recycle. The overhead fractions are re-distilled using the column, the ortho- and meta-isomers being separated and sent to storage.

The controlling factors in the process are the nitration temperature and the mixed-acid concentration. Subsequent operations for isomer separation and purification are controlled by the crystallization points of the still and crystallizer liquors.

METHOD A

BATCH PROCESS

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PROCESS DATA

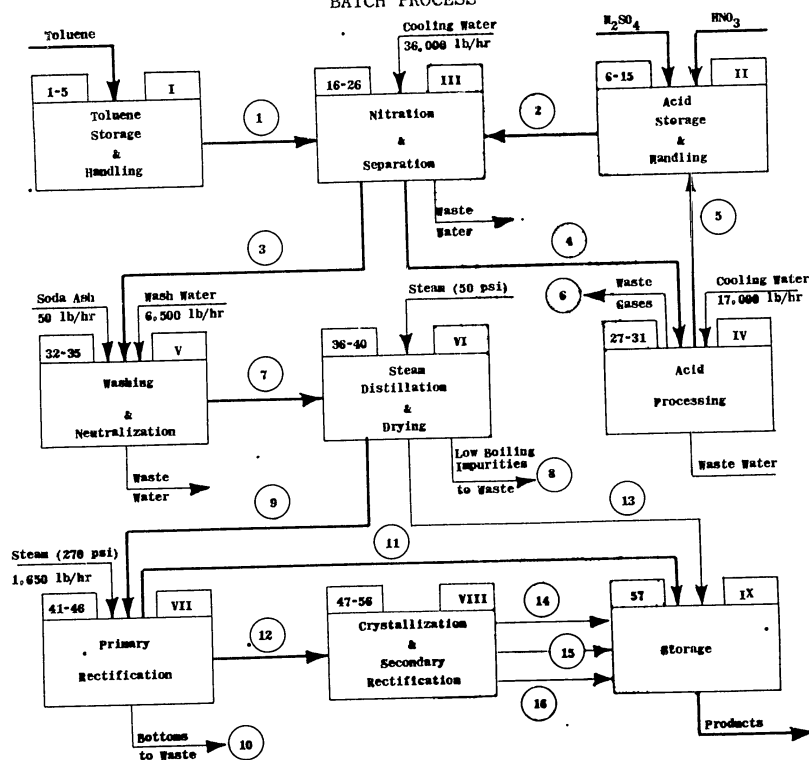
Standardized tables containing the results of our study of the Soviet process for the production of mononitrotoluenes by the batch process are presented in this section. Tables VIII. A.1-VIII. A.4, which follow, tabulate the process data in terms of input-output quantities.

While the technical details of the process have been drawn from German and Soviet practice (1,3), the equipment information has been derived primarily from US sources (4). Wherever possible, auxiliary-item inputs, such as piping, electricals, maintenance, etc., have been estimated from over-all factors derived from US experience, with appropriate adjustment for Soviet practice. Detailed descriptions of methods of sizing equipment and computing the corresponding values of weights and labor of installation are presented in our Chemical Process Calculation Manual (4). Where it has been necessary to approximate the input quantities for a special item of equipment, such as a furnace, or to estimate certain over-all factors from US practice, this is indicated by an asterisk (\*) following the item number in the Capital-Items table. In general, calculations of this nature will only be shown in our basic process engineering work sheets.

Process information actually derived from Soviet sources is indicated by reference. We have provided for the estimation of major differences between US and Soviet practice by means of average labor- and weight-conversion factors. Thus, while the majority of the Capital-Items information is expressed on a US basis, the Capital-Summary figures are, for the most part, estimates of actual Soviet practice. The last is also true of the Material-Summary and General-Process-Items information. In general, we have been able to derive reliable estimates of Soviet items falling in CEIR Code Categories 02 (Machinery, excluding Electrical), 03 (Electrical Machinery, Equipment and Supplies), 06 (Fabricated Metal Products), 07 (Chemicals), 08 (Metals, Primary and Secondary), 18 (Metal Ores and Concentrates), 19 (Non-metallic Minerals), as well as materials and labor involved in building construction.

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FIGURE VIII.A.1  
MONONITROTOLUENES  
BATCH PROCESS



Flow Rates (lb/hr)								
Material	1	2	3	4	5	6	7	8
Toluene	1,710		15				15	15
Nitric Acid		1,155		5		5		
Sulfuric Acid		2,070	20	2,050	2,020	30		
Water		615	10	935	150	785	20	20
Paraffin	15		15				15	15
Impurities	15		50				35	
O-Nitrotoluene			1,517				1,507	2
M-Nitrotoluene			90				90	
P-Nitrotoluene			838				833	3

Flow Rates (lb/hr)								
Material	9	10	11	12	13	14	15	16
Impurities	12	12			23			
O-Nitrotoluene	585	12	340	33	920	33		
M-Nitrotoluene	33	3	3	25	37			23
P-Nitrotoluene	330	5	3	320	500		320	

NOTE: In the small blocks in the diagram above, Roman numerals refer to operations in TABLE VIII.A.2; Arabic numerals correspond to Process Equipment Items.

MONONITROTOLUENESBATCH PROCESSTABLE VIII. A. 1CAPITAL SUMMARY

<u>CEIR Code</u>	<u>CEIR Commodity</u>	<u>Quantity</u>	<u>Units</u>
0201	Machine Tools	4.50	MT
0209	Pumps and Compressors	2.57	MT
0222	Industrial Machinery, NEC	93.2	MT
0225	Replacement Parts for Other 02 Commodities	2.64	MT
0301	Motors and Generators	1.41	MT
0305	Electrical Measurement and Control Apparatus	1.26	MT
0310	Electrical Machinery and Equipment, NEC	34.5	MT
0404	Freight Cars	1	U
0406	Trucks	1	U
0407	Passenger Cars	1	U
0501	Mechanical Measuring and Control Instruments	1.68	MT
0610	Tanks	88.4	MT
0612	Metal Fabrication for Construction	0.192	TMT
0717	Paints, Varnishes	2.92	MT
0805	Ordinary Steel Finished Shapes	0.160	TMT
0806	Quality Steel Finished Shapes	0.00536	TMT
0808	Iron, Steel Forgings	0.0137	TMT
0809	Iron Castings	0.0078	TMT
0811	Primary Copper	3.61	MT
0812	Primary Lead	0.645	MT
0813	Primary Zinc	1.37	MT
0826	Non-Ferrous Rolling, Drawing	0.353	CM
0827	Non-Ferrous Casting	0.293	CM

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TABLE VIII. A. 1 (Continued)

CEIR Code	CEIR Commodity Group	Quantity	Units
1010	Petroleum Coke Residuals, NEC	0.00770	TMT
1401	Round Timber	0.0326	TCM
1402	Saw-Mill Products	0.145	TMT
1403	Wood Products	0.00473	TMT
1404	Furniture	1.67	MT
1601	Refractories	0.0170	TMT
1603	Cement	0.275	TMT
1604	Brick and Hollow Tile	0.480	TMT
1605	Gypsum Products	0.0142	TMT
1606	Lime	0.0301	TMT
1608	Flat Glass	2.63	MT
1609	Non-Metallic Construction Materials, NEC	0.725	TMT
1905	Stone, Sand, and Gravel	3.00	TMT
2300	Services (Incl. Engineering)(US Basis)(a)	0.0152	TMY
2400	Labor (USSR Basis)(a)	0.101	TMY

(a) See Table VIII. A. 2, Footnote (e).

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## MONONITROTOLUENES

## BATCH PROCESS

TABLE VIII. A. 2

## CAPITAL ITEMS

Item No.	Process Equipment(a)	CEIR Code	Quantity(b)	Installation Labor (Man-Hr)
Operation I - Toluene Storage and Handling				
1	Storage Tank (33,500 gal)	0612 0805	(7.50) 7.50	400
2	Pump, Centrifugal (35 gpm @ 40 ft head)	0209 0301	0.08 0.05	10
3	Storage Tank (5600 gal)	0610	1.61	84
4	Pump, Centrifugal (4; ea 12 gpm @ 40 ft head)	0209 0301	0.32 0.20	36
5	Feed Tank (4; ea 700 gal)	0610	1.38	64
Operation II - Acid Storage and Handling				
6	Storage Tank, Nitric Acid (21,200 gal, acid-resistant)	0610	5.16	170
7	Pump, Centrifugal (22 gpm @ 75 ft head, acid resistant)	0209 0301	0.08 0.05	10
8	Storage Tank, Nitric Acid (3600 gal, acid-resistant)	0610	1.12	52
9	Storage Tank, 98% Sulfuric Acid (20,000 gal)	0610	5.04 STAT	170

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TABLE VIII.A.2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Operation II - Acid Storage and Handling (Cont'd)</u>				
10	Pump, Centrifugal (20 gpm @ 95 ft head, acid-resistant)	0209 0301	0.08 0.05	10
11	Storage Tank, Sulfuric Acid (3500 gal)	0610	1.09	50
12	Pump, Centrifugal (2; acid-metering to mixed-acid tank)	0209 0301	0.08 0.05	10
13	Storage Tank, Mixed Acid (6700 gal, acid-resistant, propeller-agitated)	0610	2.60	114
14	Pump, Centrifugal (4; ea 15 gpm @ 85 ft head, acid-resistant)	0209 0301	0.32 0.20	36
15	Feed Tank, Mixed Acid (4; ea 850 gal, acid-resistant)	0610	1.58	72
<u>Operation III - Nitration and Separation</u>				
16 *	Nitrator (4; ea 1900 gal, cast-iron with mild-steel cooling jacket, cast-iron stirrer; lead cooling coils, 320 sq ft heat-transfer area)	0610	22.6	300
17	Separator (4; ea 1600 gal, lead-lined-steel, conical bottom)	0610	6.24	140
18	Pump, Centrifugal (2; ea 15 gpm @ 50 ft head, acid-resistant)	0209 0301	0.16 0.10	20
19	Assembly Tank, Acid Nitrotoluenes (2; ea 1600 gal, lead-lined-steel)	0610	2.42	116
20	Assembly Tank, Spent Acid (2; ea 1400 gal, lead-lined-steel)	0610	2.23	102

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TABLE VIII.A.2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Operation III - Nitration and Separation (Cont'd)</u>				
21	Pump, Centrifugal (2; ea 40 gpm @ 20 ft head, acid-resistant)	0209 0301	0.16 0.10	20
22	Settling Tank, Spent Acid (2; ea 5500 gal, lead-lined-steel)	0610	6.64	660
23	Pump, Centrifugal (1 gpm @ 20 ft head, acid-resistant)	0209 0301	0.08 0.05	10
24	Pump, Centrifugal (2; ea 75 gpm @ 100 ft head, acid-resistant)	0209 0301	0.16 0.10	20
25	Storage Tank, Spent Acid (2; ea 5500 gal, lead-lined-steel)	0610	6.64	660
26	Pump, Centrifugal (5 gpm @ 50 ft head, acid-resistant)	0209 0301	0.08 0.05	10
<u>Operation IV - Acid Processing</u>				
27 *	Scrubber, Acid Vapor (300 SCFM, acid-resistant)	0222	0.15	10
28 *	Retort (5.3 ft diam x 23.5 ft, 3 compartments, lead-lined-steel with lining of acid-resistant brick, direct contact of fuel gas with countercurrent acid flow, 500°F operating temperature)	0209 0222 0301 0612 0805 0806 0812 0826 1601	0.16 0.59 0.20 (3.47) 2.30 0.21 0.86 (0.08) (CM) 17.0 )	461
29	Cooler (55 sq ft heat-transfer area)	0222	0.08	15

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TABLE VIII. A. 2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Operation IV - Acid Processing (Cont'd)</u>				
30	Pump, Centrifugal (5 gpm @ 50 ft head, acid-resistant)	0209 0301	0.08 0.05	10
31	Storage Tank, 93% Sulfuric Acid (3200 gal)	0610	1.75	92
<u>Operation V - Washing and Neutralization</u>				
32(c)	Washer (2; ea 4000 gal, lead-lined-steel, equipped for steam-distillation)	0610	2.50	138
33	Solution Tank, Sodium Hydroxide (250 gal, propeller-agitated)	0610	0.44	19
34	Pump, Centrifugal (2; ea 15 gpm @ 20 ft head)	0209 0301	0.16 0.10	20
35	Assembly Tank, Crude Nitrotoluenes (2; ea 21,000 gal)	0610	10.20	408
<u>Operation VI - Steam Distillation<sup>(c)</sup> and Drying</u>				
36	Pump, Centrifugal (2; ea 15 gpm @ 20 ft head)	0209 0301	0.16 0.10	20
37	Vacuum Dryer (2; ea 6600 gal, 1.57 in. Hg working pressure)	0222	20.60	940
38	Ejector (2; ea 1.57 in. Hg working pressure)	0209	0.52	20
39	Pump, Centrifugal (2; ea 15 gpm @ 20 ft head)	0209 0301	0.16 0.10	20
40	Pump, Centrifugal (2; ea 100 gpm @ 20 ft head)	0209 0301	0.16 0.10	20

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TABLE VIII. A. 2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Operation VII - Primary Rectification</u>				
41	Distillation Column (6.5 ft diam x 54 ft, 40 plates, cast-iron with dephlegmator)	0222	71.92	1,500
42	Reboiler (300 sq ft heat-transfer area, cast-iron 4.72 in. Hg working pressure)	0222	2.30	57
43	Ejector (0.59 in. Hg working pressure)	0209	0.13	8
44	Condenser (180 sq ft heat-transfer area, cast-iron)	0222	0.19	38
45	Cooler (65 sq ft heat-transfer area)	0222	0.09	17
46	Storage Tank, Crude p-Nitrotoluene (6300 gal)	0610	1.78	92
<u>Operation VIII - Crystallization and Secondary Rectification</u>				
47	Crystallizer, Vertical, Multitube (2; ea 8 ft diam x 18 ft, 2200 gal, 312 tubes ea 3 in. diam)	0610	22.30	1,280
48	Centrifuge, Basket Type (2; ea 100 gal)	0222	1.20	720
49	Storage Tank, Crystallizer Liquor (3000 gal)	0610	0.97	54
50	Pump, Centrifugal (100 gpm @ 20 ft head)	0209 0301	0.08 0.05	10
51	Distillation Column (3.5 ft diam x 27 ft, 40 plates, cast-iron)	0222	21.68	470
52	Reboiler (60 sq ft heat-transfer area, cast-iron, 4.72 in. Hg working pressure)	0222	0.53	17
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TABLE VIII.A.2 (Continued)

Item No.	Process Equipment(a)	CEIR Code	Quantity(b)	Installation Labor (Man-Hr)
<u>Operation VIII - Crystallization and Secondary Rectification (Cont'd)</u>				
53	Ejector (0.59 in. Hg working pressure)	0209	0.05	8
54	Condenser (11 sq ft heat-transfer area, cast-iron)	0222	0.32	5
55	Pump, Centrifugal (2; ea 50 gpm @ 20 ft head)	0209 0301	0.16 0.10	20
56	Assembly Tank (1; 1000 gal - 1; 800 gal)	0610	0.82	46
<u>Operation IX - Storage</u>				
57	Storage Tank (2; ea 21,000 gal - 1; 18,000 gal - 1; 1650 gal - 1; 1000 gal)	0610	10.78	468
Total Weight of Process Equipment (exclusive of CEIR Codes 0612 and 0826)			270.63 MT	
Total Labor for Installation of Process Equipment				10,349
<u>Auxiliary Items</u>				
58	Improved Land			6,010
59	Ventilation:			
	Stack (60 ft)	0222	2.00	
	Ducts (30 in. sq x 220 ft)	0612 0805	(1.61) 1.61	
	Fans and Blowers (9330 SCFM @ 3 in. H <sub>2</sub> O head)	0222 0301	1.52 0.08	482

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TABLE VIII.A.2 (Continued)

Item No.	Process Equipment(a)	CEIR Code	Quantity(b)	Installation Labor (Man-Hr)
<u>Auxiliary Items</u>				
60	Pipe, Valves and Fittings:			
	Metal Fabrication for Construction	0612	(129. )	
	Ordinary Steel Finished Shapes	0805	.86.4 )	
	Quality Steel Finished Shapes	0806	7.14 )	
	Iron, Steel Forgings	0808	18.2 )	
	Iron Castings	0809	10.4 )	
	Primary Copper	0811	4.81 )	
	Primary Zinc	0813	1.82 )	
	Non-Ferrous Rolling, Drawing	0826	( 0.390)(CM)	
	Non-Ferrous Casting	0827	( 0.390)(CM)	
	Non-Metallic Construction Material, NEC	1609	1.17 )	18,100
61	Foundations for Equipment:			
	Reinforcing Rod	0612	( 28.0 )	
	Cement	0805	28.0 )	
	Sand, Stone, and Gravel	1603	72.0 )	
		1905	600. )	3,300
62	Paint	0717	2.92	2,710
63	Insulation for Equipment and Piping	1609	6.77	3,000
64	Structural Steel for Equipment	0612 0805	( 25.7 ) 25.7 )	1,400
65	Electrical (Motors less than 5 hp and miscellaneous electrical supplies)	0310	46.0	7,690
66	Instruments	0305 0501	1.68 ) 1.68 )	2,400
67	Maintenance:			
	Machine Tools	0201	6.0	1,500
	Replacement Parts for Other 02 Commodities	0225	STAT <sup>52</sup>	

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TABLE VIII.A.2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Auxiliary Items (Cont'd)</u>				
68	Buildings (17,500 sq ft floor area) <sup>(d)</sup>			
	Ordinary Steel Finished Shapes	0612	(45.9 )	
		0805	45.9 )	
	Petroleum Coke Residuals, NEC	1010	7.70 )	
	Round Timber	1401	32.6 ) (CM)	
	Saw-Mill Products	1402	145. )	
	Wood Products	1403	4.73 )	
	Cement	1603	203. )	
	Brick, Hollow Tile	1604	480. )	
	Gypsum Products	1605	14.2 )	
	Lime	1606	30.1 )	
	Flat Glass	1608	2.63 )	
	Non-Metallic Construction Material, NEC	1609	716. )	
	Sand, Stone, and Gravel	1905	2,400. )	
	Office Furniture	1404	1.67 )	86,300
69	Plant Transportation:			
	Fork Lift	0222	1.0	
	Tank Car	0404	1 (U)	
	Truck	0406	1 (U)	
	Passenger Car	0407	1 (U)	
70	Services (Includes Engineering)	2300		36,500
<u>Installation Labor Summary<sup>(d)</sup></u>				
	USSR Basis	2400		86,300
	US Basis	2400		(56,900)
	US Normalized to USSR Basis	2400		156,500
	Total Installation Labor USSR Basis	2400		242,800

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TABLE VIII.A.2 (Continued)

## NOTES:

- (a) Material of construction is mild steel unless otherwise specified. All equipment-weight and labor-of-installation data are US basis unless otherwise specified. A factor of 0.75 is used to convert the weight of metallic items in this table to the USSR basis presented in the Capital Summary table (4).
- (b) Metric tons (MT) unless otherwise noted.
- (c) Steam distillation is carried out in the same equipment used for washing.
- (d) Data are USSR basis except for the estimated floor area.
- (e) Installation labor on Buildings is based on USSR practice; all other installation labor is based on US practice. The installation labor reported for CEIR Code 2400 in the Capital Summary table is on a USSR basis, US labor being converted to USSR labor by applying a normalizing factor of 2.75 (4). Labor under CEIR Code 2300 is on a US basis in all tables.

STAT

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MONONITROTOLUENESBATCH PROCESSTABLE VIII. A. 3MATERIAL SUMMARY

Material Input				
Material	Input/30 days		Code	Specification
	Quantity	Units		
Toluene	567	MT	1006	Technical (98.3% Toluene)
Soda Ash	17.0	MT	0705	Technical (95% Na <sub>2</sub> CO <sub>3</sub> )
Nitric Acid	0.527	TMT	0704	Technical (71% HNO <sub>3</sub> )
Sulfuric Acid	0.0176	TMT	0703	Technical (92-93% H <sub>2</sub> SO <sub>4</sub> )
Maintenance	1.73	MT	0225	Replacement Parts
Material Output				
Material	Output/30 days		CEIR Code	Specification
	Quantity	Units		
Mixed Mono-nitrotoluenes	489	MT	0714	Commercial (61.3% o-, 33.3% p-, 3.8% m-Nitrotoluene, and 1.6% impurities)
o-Nitrotoluene	179.3	MT	0714	Technical (98.2% o-Nitrotoluene)
p-Nitrotoluene	104.4	MT	0714	CP
o-Nitrotoluene	10.77	MT	0714	CP
m-Nitrotoluene	8.15	MT	0714	CP

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MONONITROTOLUENESBATCH PROCESSTABLE VIII. A. 4GENERAL PROCESS ITEMS

Rated Annual Capacity, Mononitrotoluenes	7,915	MT <sup>(a)</sup>
Proportion of rated annual capacity realizable:		
1st year	75	%
2nd year	85	%
3rd year	95	%
4th year	98	%
Maximum Realizable Short-Term Capacity	103	%
Labor Input to Process <sup>(b)</sup> :		
US Basis	100,600	Man-Hr/Yr (4)
USSR Basis	301,800	Man-Hr/Yr (4)
Labor Scale Factor	0.7 <sup>(c)</sup>	
Range of applicability of scale factor:		
Lower limit	0.2 <sup>(d)</sup>	
Upper limit	2.0 <sup>(d)</sup>	
Electrical Input Per Year	1,740,000	KWH (3)
Water Input Per Year	194,000	MT
Net Fuel Input Per Year (as steam)	163,000	MM BTU (3)
Process Heat Other Than Steam	14,000	MM BTU
Time Required to Build New Plant	12	Months

(a) Based on 300 days per year operation at 100% mechanical efficiency, see Table VIII. A. 3 for product types.

(b) Assumes a non-automated plant.

(c) Exponential factor for rated annual plant capacity.

(d) Multiplicative factor for rated annual plant capacity. STAT

METHOD B

CONTINUOUS PROCESS

STAT

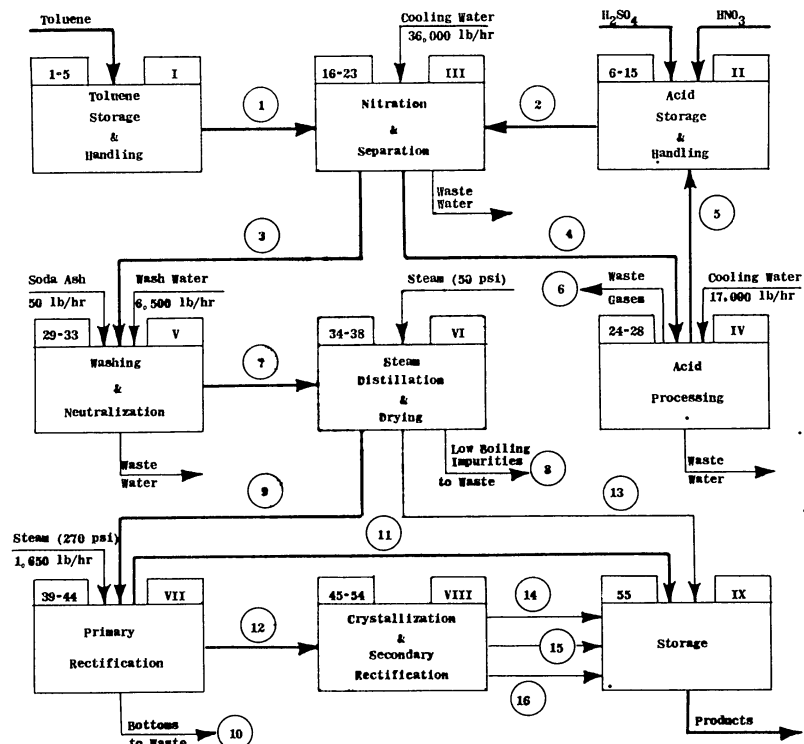
PROCESS DATA

Standardized tables containing the results of our study of the Soviet process for the production of mononitrotoluenes by the continuous process are presented in this section. Tables VIII. B. 1-VIII. B. 4, which follow, tabulate the process data in terms of input-output quantities.

While the technical details of the process have been drawn from German and Soviet practice (1, 3), the equipment information has been derived primarily from US sources. Wherever possible, auxiliary-item inputs, such as piping, electricals, maintenance, etc., have been estimated from over-all factors derived from US experience, with appropriate adjustment for Soviet practice. Detailed descriptions of methods of sizing equipment and computing the corresponding values of weights and labor of installation are presented in our Chemical-Process Calculation Manual (4). Where it has been necessary to approximate the input quantities for a special item of equipment, such as a furnace, or to estimate certain over-all factors from US practice, this is indicated by an asterisk (\*) following the item number in the Capital-Items table. In general, calculations of this nature will only be shown in our basic process engineering work sheets.

Process information actually derived from Soviet sources is indicated by reference. We have provided for the estimation of major differences between US and Soviet practice by means of average labor- and weight-conversion factors. Thus, while the majority of the Capital-Items information is expressed on a US basis, the Capital-Summary figures are, for the most part, estimates of actual Soviet practice. The last is also true of the Material-Summary and General-Process-Items information. In general, we have been able to derive reliable estimates of Soviet items falling in CEIR Code Categories 02 (Machinery, excluding Electrical), 03 (Electrical Machinery, Equipment and Supplies), 06 (Fabricated Metal Products), 07 (Chemicals), 08 (Metals, Primary and Secondary), 18 (Metal Ores and Concentrates), 19 (Non-Metallic Minerals), as well as materials and labor involved in building construction.

FIGURE VIII.B.1  
MONONITROTOLUENES  
CONTINUOUS PROCESS



Flow Rates (lb/hr)								
Material	1	2	3	4	5	6	7	8
Toluene	1,710		15				15	15
Nitric Acid		1,155		5		5		
Sulfuric Acid		2,070	20	2,050	2,020	30		
Water		615	10	935	150	785	20	20
Paraffin	15		15				15	15
Impurities	15		50				35	
O-Nitrotoluene			1,517				1,507	2
M-Nitrotoluene			90				90	
P-Nitrotoluene			838				833	3

Flow Rates (lb/hr)								
Material	9	10	11	12	13	14	15	16
Impurities	12	12			23			
O-Nitrotoluene	585	12	540	33	920	33		
M-Nitrotoluene	33	3	5	25	57			25
P-Nitrotoluene	330	5	5	320	500		320	

NOTE: In the small blocks in the diagram above, Roman numerals refer to operations in TABLE VIII.B.2; Arabic numerals correspond to Process Equipment Items.

MONONITROTOLUENES  
CONTINUOUS PROCESS

TABLE VIII. B. 1

CAPITAL SUMMARY

<u>CEIR Code</u>	<u>CEIR Commodity Group</u>	<u>Quantity</u>	<u>Units</u>
0201	Machine Tools	4.50	MT
0209	Pumps and Compressors	1.87	MT
0222	Industrial Machinery, NEC	94.0	MT
0225	Replacement Parts for Other 02 Commodities	2.27	MT
0301	Motors and Generators	0.945	MT
0305	Electrical Measurement and Control Apparatus	1.09	MT
0310	Electrical Machinery and Equipment, NEC	29.8	MT
0404	Freight Cars	1	U
0406	Trucks	1	U
0407	Passenger Cars	1	U
0501	Mechanical Measuring and Control Instruments	1.44	MT
0610	Tanks	60.8	MT
0612	Metal Fabrication for Construction	0.174	TMT
0717	Paints, Varnishes	2.52	MT
0805	Ordinary Steel Finished Shapes	0.145	TMT
0806	Quality Steel Finished Shapes	0.00478	TMT
0808	Iron, Steel Forgings	0.0118	TMT
0809	Iron Castings	0.00672	TMT
0811	Primary Copper	3.11	MT
0812	Primary Lead	0.645	MT
0813	Primary Zinc	1.18	MT
0826	Non-Ferrous Rolling, Drawing	0.312	CM
0827	Non-Ferrous Casting	0.252	CM
1010	Petroleum Coke Residuals, NEC	0.00748	TMT
		STAT	

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TABLE VIII. B. 1 (Continued)

CEIR Code	CEIR Commodity Group	Quantity	Units
1401	Round Timber	0.0316	TCM
1402	Saw-Mill Products	0.141	TMT
1403	Wood Products	0.00459	TMT
1404	Furniture	1.62	MT
1601	Refractories	0.0170	TMT
1603	Cement	0.261	TMT
1604	Brick and Hollow Tile	0.466	TMT
1605	Gypsum Products	0.0138	TMT
1606	Lime	0.0292	TMT
1608	Flat Glass	2.55	MT
1609	Non-Metallic Construction Materials, NEC	0.702	TMT
1905	Stone, Sand, and Gravel	2.88	TMT
2300	Services (including Engineering) (US Basis) <sup>(a)</sup>	0.0152	TMY
2400	Labor (USSR Basis) <sup>(a)</sup>	0.0921	TMY

(a) See Table VIII. B. 2, Footnote (e).

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## MONONITROTOLUENES

## CONTINUOUS PROCESS

TABLE VIII. B. 2

## CAPITAL ITEMS

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Operation I - Toluene Storage and Handling</u>				
1	Storage Tank (33,500 gal)	0612 0805	(7.50) 7.50	400
2	Pump, Centrifugal (35 gpm @ 40 ft head)	0209 0301	0.08 0.05	10
3	Storage Tank (5600 gal)	0610	1.61	84
4	Pump, Centrifugal (12 gpm @ 40 ft head)	0209 0301	0.08 0.05	10
5	Feed Tank (250 gal)	0610	0.12	0
<u>Operation II - Acid Storage and Handling</u>				
6	Storage Tank, Nitric Acid (21,200 gal, acid-resistant)	0610	5.16	170
7	Pump, Centrifugal (22 gpm @ 75 ft head, acid-resistant)	0209 0301	0.08 0.05	10
8	Storage Tank, Nitric Acid (3600 gal, acid-resistant)	0610	1.12	52
9	Storage Tank, 98% Sulfuric Acid (20,000 gal)	0610	5.04	170
10	Pump, Centrifugal (20 gpm @ 95 ft head, acid-resistant)	0209 0301	0.08 0.05	10
11	Storage Tank, Sulfuric Acid (3500 gal, acid-resistant)	0610	STAT 9	50

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TABLE VIII. B. 2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
12	Pump, Centrifugal (2; acid-metering to mixed-acid tank)	0209 0301	0.08 0.05	10
13	Storage Tank, Mixed Acid (6700 gal, acid-resistant, propeller-agitated)	0610	2.60	114
14	Pump, Centrifugal (15 gpm @ 85 ft head, acid-resistant)	0209 0301	0.08 0.05	10
15	Feed Tank, Mixed Acid (300 gal, acid-resistant)	0610	0.17	9
<u>Operation III - Nitration and Separation</u>				
16*	Nitrator, Schmidt-Meissner Type (2; ea 110 gal, stainless-steel, propeller-agitated, cooling coils, 50 sq ft heat-transfer area)	0610	0.76	30
17	Separator, Schmidt-Meissner Type (350 gal, stainless-steel with vertical vanes and constant-head overflow device)	0222	0.22	20
18	Settling Tank, Spent Acid (2; ea 5500 gal, lead-lined steel)	0610	6.64	660
19	Pump, Centrifugal (1 gpm @ 20 ft head, acid-resistant)	0209 0301	0.08 0.05	10
20	Assembly Tank, Acid Nitrotoluenes (50 gal, lead-lined-steel)	0610	0.12	8
21	Pump, Centrifugal (75 gpm @ 100 ft head, acid-resistant)	0209 0301	0.08 0.05	10
22	Storage Tank, Spent Acid (2; ea 5500 gal, lead-lined-steel)	0610	6.64	660
23	Pump, Centrifugal (5 gpm @ 50 ft head, acid-resistant)	0209 0301	0.08 0.05	10

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TABLE VIII. B. 2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Operation IV - Acid Processing</u>				
24*	Scrubber, Acid Vapor (300 SCFM, acid-resistant)	0222	0.15	10
25*	Retort (5.3 ft diam x 23.5 ft, 3 compartments, lead-lined-steel with lining of acid-resistant brick, direct contact of fuel gas with countercurrent acid flow, 500°F operating temperature)	0209 0222 0301 0612 0805 0806 0812 0826 1601	0.16 0.59 0.20 (3.47) 2.30 0.21 0.86 0.08(CM) 17.00	461
26	Cooler (55 sq ft heat-transfer area)	0222	0.08	15
27	Pump, Centrifugal (5 gpm @ 50 ft head, acid-resistant)	0209 0301	0.08 0.05	10
28	Storage Tank, 93% Sulfuric Acid (3200 gal)	0610	1.75	92
<u>Operation V - Washing and Neutralization</u>				
29	Washer, Schmidt-Meissner Type (3; each 75 gal, stainless steel, 10 plates, air agitated)	0222	0.60	31
30	Rotary Air Compressor (2 SCFM @ 10 ft head)	0209 0301	0.11 0.03	10
31	Separator, Schmidt-Meissner Type (3; ea 115 gal, stainless-steel)	0222	0.30	20
32	Solution Tank, Sodium Hydroxide (250 gal, propeller-agitated)	0610	0.44	19
33 <sup>(c)</sup>	Assembly Tank, Crude Nitrotoluenes (2; ea 20,000 gal, equipped for steam distillation)	0610	STAT. 11.20	432

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TABLE VIII. B. 2 (Continued)

Item No.	Process Equipment (a)	CEIR Code	Quantity (b)	Installation Labor (Man-Hr)
<u>Operation VI - Steam Distillation (c) and Drying</u>				
34	Pump, Centrifugal (2; ea 15 gpm @ 20 ft head)	0209 0301	0.16 0.10	20
35	Vacuum Dryer (2; ea 6600 gal, 1.57 in. Hg working pressure)	0222	20.60	940
36	Ejector (2; ea 1.57 in. Hg working pressure)	0209	0.52	20
37	Pump, Centrifugal (2; ea 15 gpm @ 20 ft head)	0209 0301	0.16 0.10	20
38	Pump, Centrifugal (2; ea 100 gpm @ 20 ft head)	0209 0301	0.16 0.10	20
<u>Operation VII - Primary Rectification</u>				
39	Distillation Column (6.5 ft diam x 54 ft, 40 plates, cast-iron with dephlegmator)	0222	71.92	1,500
40	Reboiler (300 sq ft heat-transfer area, cast-iron, 4.72 in. Hg working pressure)	0222	2.30	57
41	Ejector (0.59 in. Hg working pressure)	0209	0.13	8
42	Condenser (180 sq ft heat-transfer area, cast-iron)	0222	0.19	38
43	Cooler (65 sq ft heat-transfer area)	0222	0.09	17
44	Storage Tank, Crude p-Nitrotoluene (6300 gal)	0610	1.78	92

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TABLE VIII. B. 2 (Continued)

Item No.	Process Equipment (a)	CEIR Code	Quantity (b)	Installation Labor (Man-Hr)
<u>Operation VIII - Crystallization and Secondary Rectification</u>				
45	Crystallizer, Vertical, Multitube (2; ea 8 ft diam x 18 ft, 2200 gal, 312 tubes, ea 3 in. diam)	0610	22.30	1,280
46	Centrifuge, Basket Type (2; ea 100 gal)	0222	1.20	720
47	Storage Tank, Crystallizer Liquor (3000 gal)	0610	0.97	54
48	Pump, Centrifugal (100 gpm @ 20 ft head)	0209 0301	0.08 0.05	10
49	Distillation Column (3.5 ft diam x 27 ft, 40 plates, cast-iron)	0222	21.68	470
50	Reboiler (60 sq ft heat-transfer area, cast-iron, 4.72 in. Hg working pressure)	0222	0.53	17
51	Ejector (0.59 in. Hg working pressure)	0209	0.05	8
52	Condenser (11 sq ft heat-transfer area, cast-iron)	0222	0.32	5
53	Pump, Centrifugal (2; ea 50 gpm @ 20 ft head)	0209 0301	0.16 0.10	20
54	Assembly Tank (1; 1000 gal - 1; 800 gal)	0610	0.82	46
<u>Operation IX - Storage</u>				
55	Storage Tank (2; ea 21,000 gal - 1; 18,000 gal - 1; 1650 gal - 1; 1000 gal)	0610	10.78	468
Total Weight of Process Equipment (exclusive of CEIR Code 0612 and 0826)			233.42 MT	
Total Labor for Installation of Process Equipment			STAT	9,456

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TABLE VIII. B. 2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Auxiliary Items</u>				
56	Improved			5,180
57	Ventilation:			
	Stack (60 ft)	0222	2.00	
	Ducts (220 ft, 30 in. sq)	0612	(1.61)	
		0805	1.61	
	Fans and Blowers (9330 SCFM at 3 in. H <sub>2</sub> O)	0222	1.52	
		0301	0.08	482
58	Pipe, Valves and Fittings:			
	Metal fabrication for construction	0612	(111. )	
	Ordinary steel finished shapes	0805	74.5	
	Quality steel finished shapes	0806	6.16	
	Iron, steel forgings	0808	15.7	
	Iron castings	0809	8.96	
	Primary copper	0811	4.15	
	Primary zinc	0813	1.57	
	Non-ferrous rolling, drawing	0826	(0.336) (CM)	
	Non-ferrous casting	0827	(0.336) (CM)	
	Non-metallic construction material, NEC	1609	1.01	15,600
59	Foundations for Equipment:			
	Reinforcing rod	0612	(25.0)	
	Cement	0805	25.0	
	Sand, stone, and gravel	1603	64.0	
		1905	550.0	2,800
60	Paint	0717	2.52	2,330
61	Insulation for Equipment and Piping	1609	5.84	2,590
62	Structural Steel for Equipment			
		0612	(23.5)	
		0805	23.5	1,280
63	Electricals (motors less than 5 hp and miscellaneous electrical supplies)			
		0310	39.7	6,630
64	Instruments			
		0305	1.45	
		0501	1.44	2,070

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TABLE VIII. B. 2 (Continued)

Item No.	Process Equipment <sup>(a)</sup>	CEIR Code	Quantity <sup>(b)</sup>	Installation Labor (Man-Hr)
<u>Auxiliary Items (Continued)</u>				
65	Maintenance:			
	Machine tools	0201	6.0	1,500
	Replacement parts for other 02 commodities	0225	3.03	
66	Buildings (17,000 sq ft floor area) <sup>(d)</sup>			
	Ordinary steel finished shapes	0612	(44.5)	
	Petroleum coke residuals, NEC	0805	44.5	
	Round timber	1010	7.48	
	Saw-mill products	1401	31.6 (CM)	
	Wood products	1402	141. )	
	Cement	1403	4.59	
	Brick, hollow tile	1603	197. )	
	Gypsum products	1604	466. )	
	Lime	1605	13.8 )	
	Flat glass	1606	29.2 )	
	Non-metallic construction material, NEC	1608	2.55	
	Sand, stone, and gravel	1609	695. )	
	Office furniture	1905	2330. )	
		1404	1.62	83,800
67	Plant Transportation:			
	Fork lift	0222	1.0	
	Tank car	0404	1 (U)	
	Truck	0406	1 (U)	
	Passenger car	0407	1 (U)	
68	Services (includes Engineering )	2300		32,500
<u>Installation Labor Summary<sup>(e)</sup></u>				
	USSR Basis	2400		83,800
	US Basis	2400		(49,900)
	US Normalized to USSR Basis	2400		137,200
	Total Installation Labor USSR Basis	2400		221,000
			STAT	

TABLE VIII. B. 2 (Continued)

## NOTES

- (a) Material of construction is mild steel unless otherwise specified. All equipment-weight and labor-of-installation data are US basis unless otherwise specified. A factor of 0.75 is used to convert the weight of metallic items in this table to the USSR basis presented in the Capital Summary table (4).
- (b) Metric tons (MT) unless otherwise noted.
- (c) Steam distillation is carried out in the assembly tank receiving the washed crude nitrotoluenes.
- (d) Data are USSR basis except for the estimated floor area.
- (e) Installation labor under Buildings is based on USSR practice; all other installation labor is based on US practice. The installation labor reported for CEIR Code 2400 in the Capital Summary table is on a USSR basis, US labor being converted to USSR labor by applying a normalizing factor of 2.75 (4). Labor under CEIR Code 2300 is on a US basis in all tables.

## MONONITROTOLUENES

## CONTINUOUS PROCESS

TABLE VIII. B. 3

## MATERIAL SUMMARY

Material	Material Input		CEIR Code	Specification
	Input/30 days Quantity	Units		
Toluene	567	MT	1006	Technical (98.3% Toluene)
Aoda Ash	17.0	MT	0705	Technical (95% Na <sub>2</sub> CO <sub>3</sub> )
Nitric Acid	0.527	TMT	0704	Technical (71% HNO <sub>3</sub> )
Sulfuric Acid	0.0176	TMT	0703	Technical (92-93% H <sub>2</sub> SO <sub>4</sub> )
Maintenance	1.49	MT	0225	Replacement Parts

Material	Material Output		Code	Specification
	Output/30 days Quantity	Units		
Mixed Mono-nitrotoluenes	489	MT	0714	Commercial (61.3% o-, 33.3% p-, 3.8% m-Nitrotoluene; 1.6% impurities)
o-Nitrotoluene	179.3	MT	0714	Technical (98.2% ortho-Nitrotoluene)
p-Nitrotoluene	104.4	MT	0714	CP
o-Nitrotoluene	10.77	MT	0714	CP
m-Nitrotoluene	8.15	MT	0714	CP
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MONONITROTOLUENES  
CONTINUOUS PROCESS

TABLE VIII.B.4

GENERAL PROCESS ITEMS

Rated Annual Capacity (Mononitrotoluenes)	7,915	MT <sup>(a)</sup>
Percent of rated annual capacity realizable:		
1st year	75	%
2nd year	85	%
3rd year	95	%
4th year	98	%
Maximum Realizable Short Term Capacity	103	%
Labor Input to Process <sup>(b)</sup>		
US Basis	76,500	Man-Hr/Yr
USSR Basis	229,500	Man-Hr/Yr (4)
Labor Scale Factor	0.7 <sup>(c)</sup>	
Range of applicability of scale factor:		
Lower limit	0.2 <sup>(d)</sup>	
Upper limit	2.0 <sup>(d)</sup>	
Electrical Input Per Year	5,210,000	KWH (3)
Water Input Per Year	194,000	MT
Net Fuel Input Per Year as Steam	988,000	MM BTU (3)
Process Heat Other Than Steam	14,000	MM BTU
Time Required to Build New Plant	12	Months

(a) Based on 300 days per year operation at 100% mechanical efficiency; see Table VIII.B.3 for product types.

(b) Assumes a non-automated plant.

(c) Exponential factor for rated annual plant capacity.

(d) Multiplicative factor for rated annual plant capacity.

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